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REVIEW OF WORLD ENGINEERING PROGRESS
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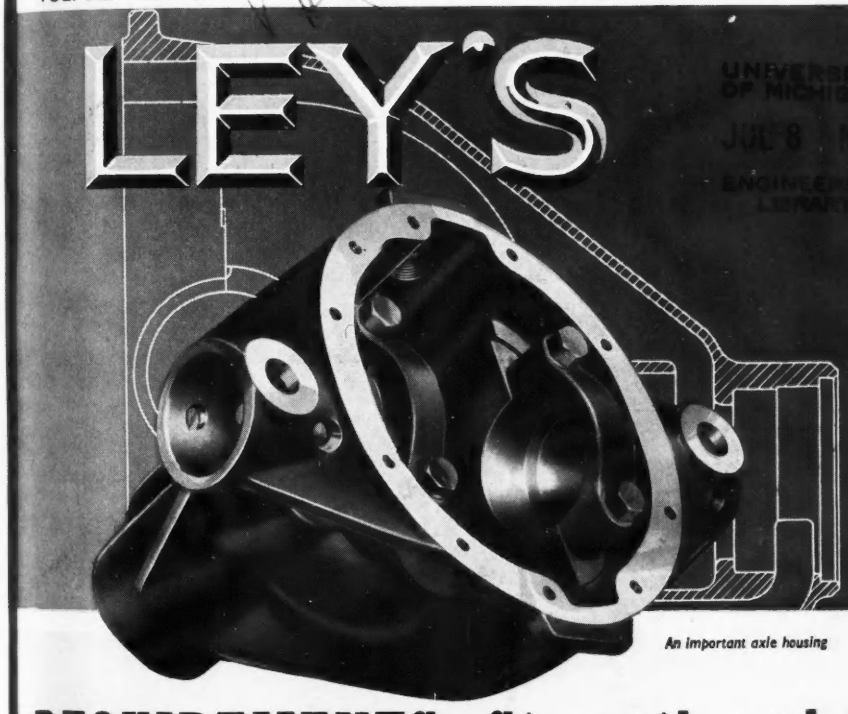

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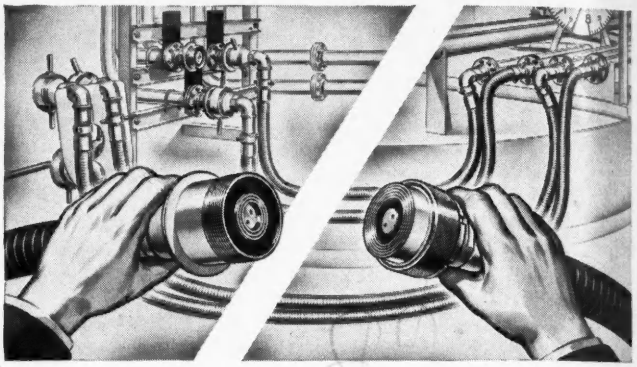

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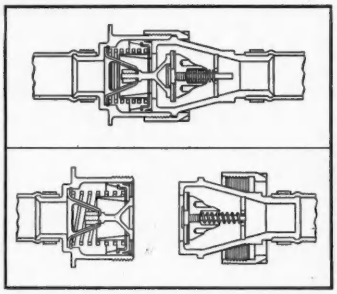

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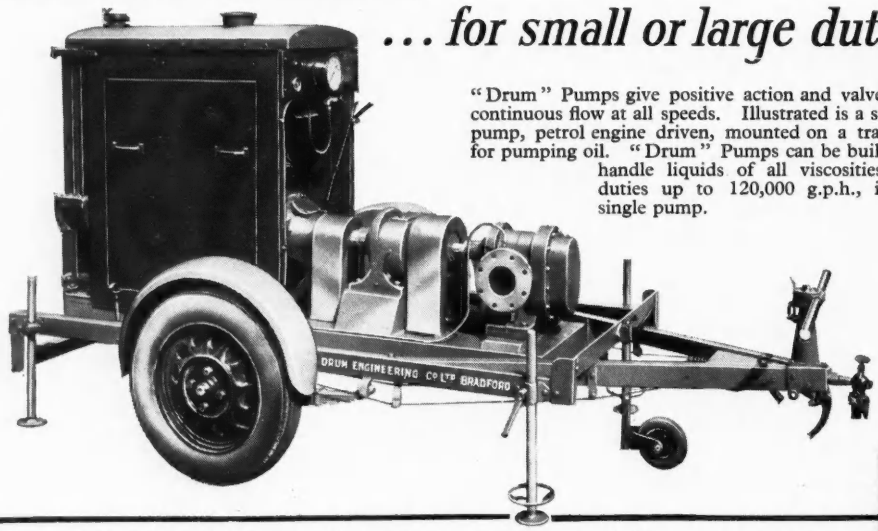

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *VAPOUR DEPOSITION*

The search for improved methods of applying refractory coatings of metals and non-metals has led to the revival of the vapour deposition process. Vapour deposition was used over 50 years ago by investigators seeking a means of forming tungsten filaments for the electric lamp industry. The method did not gain commercial acceptance, however, and vapour deposition was neglected until recent years. Vapour deposition can be described as the formation of a coating by chemical reaction at a heated surface. Thus, a metal coating may be applied by passing a volatile metal chloride and hydrogen over a heated underbody. As the temperature need only be high enough to produce a reasonable reaction rate, the deposition process may be carried out far below the melting point of the material to be deposited. Thus, for instance, tantalum, which has a melting point of 3,000° C, can be deposited at temperatures as low as 500 to 600° C. Although the coatings are deposited at temperatures below the melting point of the coating material, they are dense and have the same properties as fused metals or compounds of comparable purity. The majority of these coating processes is carried out at atmospheric pressure. In many cases, a carrier is used which may be an inert gas such as helium, or it may be reactive, as when excess hydrogen is used as the carrier in halide reductions. The specimen is best heated internally, induction or resistance heating being most commonly used. Metals, with the exception of osmium, ruthenium, and probably iridium, can be deposited in ductile form. They can be made hard and brittle, however, by the addition of traces of carbon, oxygen, nitrogen, or hydrogen compounds to the plating atmosphere.

● *MACHINING JET ENGINE PARTS*

There is no doubt that new tooling methods and machines will have to be devised if jet engine parts are to be built in larger quantities than heretofore. New machine tools will have to be designed to cope with the exigencies arising from the use of tougher alloys, components of larger diameter and thinner wall sections, and the need for higher production rates. It is well known, for instance, that the contour machining of discs is difficult when done by hand feeding, but this need not be so if means are provided for controlling the operation from a master tracing. Today many automatic feeding heads are available for this purpose, such as cams, templates, magnetic wire, punched tape and other control devices. It is therefore recommended that machine tool designers should decide on the most promising automatic control system available and then start producing this equipment in volume. Another problem which, in spite of its obviousness, has not received sufficient attention in the past is the automatic removal of chips from the automatic machine tool. Also, there is, of course, the machining of titanium and its alloys, which, in the not too distant future, will become an outstanding material in jet engine construction. Although a certain amount of experience has been gained in this respect, the machining of these materials still presents difficulties. This is due to the fact that titanium carbide is harder than the tungsten carbide found in most tools, so that excessive tool wear results. While no information on the spark machining of these alloys has become available as yet, it would appear that this method, once it has become fully commercially available, should hold particular promise in this field.

● *COLD-DRIVEN LARGE ALUMINIUM RIVETS*

Experience during the last war, especially in the aircraft industry, taught fabricators a great deal about the use of aluminium rivets, but as recently as five years ago it was still not possible to use aluminium rivets larger than about $\frac{3}{8}$ in. in diameter. In consideration of the practical difficulties connected with the use of either hot or frozen riveting, research was concentrated upon the development of a cold riveting method. A most satisfactory solution to the problem was found in the development of the annular point rivet which permits cold driving of aluminium rivets up to 1 in. diameter using standard riveting guns with only slight modifications. The new rivet was originally developed for use in an all-aluminium bridge in Canada and since then has been widely used in larger sizes for railway and shipbuilding purposes as well as numerous other applications. As the name suggests, the point or driven head of the new rivet is of annular shape and its driving involves the use of a specially designed riveting set with a curved profile leading to a central tip which is inserted in a hole drilled in the shank of the rivet. The pneumatic hammer or gun is not held in line with the longitudinal

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axis of the rivet while it is being driven, but is rolled about this axis at an angle of about 8 to 10 deg. The ultimate possibilities of annular point rivets will be discovered only in time, but even the first application proved that a two-man crew could cold-drive rivets of the new type as fast as a four-man crew could drive the alternative hot steel rivets.

● *ELECTRONIC AIRSPEED INDICATOR*

The specification of a British patent just published describes a highly interesting improvement of a true airspeed indicator for aircraft. In this design, the velocity of aircraft is indicated by measuring the time interval required by a group of ions generated at one point to be carried by the air stream to a second point. For this purpose, a source of radioactive material is placed at the upstream point of the device, the alpha particles emitted by the radio-active material ionizing the air of the slipstream passing through the device. At a point downstream, a first screen or electrode is placed, which is charged with alternating current of approximately 250 volts. At a distance downstream from the first electrode, a second electrode is placed, which is in line with the first electrode and the radioactive material. The bombardment of the air by the alpha particles creates approximately equal amounts of positive and negative particles. These charges travel along with the slipstream until they reach the first electrode. Depending upon the polarity of the screen voltage at a given instant, either the positive or the negative charges will be attracted to the electrode. After passing over the first electrode, the airstream will therefore consist of groups of positive charges containing a few negative charges, alternating with groups of negative charges including a few positive charges, and so on. When passing through a second screen or electrode, the slipstream will therefore induce a periodically varying voltage in the second electrode. As the distance between the electrodes is fixed, measurement of the phase difference of the energizing voltage applied to the first electrode and the voltage induced in the second electrode will provide a measure of the true airspeed.

● *X-RAY FLUORESCENCE ANALYSIS*

The non-destructive technique of X-ray fluorescence analysis is finding increasing application in industry for the rapid quantitative analysis of high-alloy steels and complex high-temperature heat-resisting alloys of the chromium-nickel-cobalt type. The test procedure consists in inserting a specimen into the apparatus, setting the analyzing crystal and the Geiger counter at proper angles to detect radiation, and measuring the intensity in counts per second. The intensity obtained is compared with that of a standard specimen of somewhat similar composition and characteristics. Operation of the equipment is said to be simple, and an average laboratory technician can operate the equipment, once an appropriate analytical technique has been established. About 3 to 5 minutes is required for the analysis of each element by this method. Fluorescence is produced by incident X-radiation of high-intensity, namely, short wavelength and high energy level. By irradiating the specimen, characteristic X-radiations of the elements contained in it are produced; then, by using X-ray diffraction methods, the various wavelengths may be separated and measured. It is possible to determine the intensities and from them to assess the percentages of each element present in the specimen. Analysis is independent of the state of the element in the sample, that is, whether it be free, combined, or alloyed. The method can be used to detect all elements from titanium to uranium, and by comparatively simple alteration, the range can be extended several elements lower in atomic number than titanium. Accuracy of analysis varies with the nature of the specimen components. Optimum accuracy, of the order of one-half of one per cent of the element present may be obtained under most favourable circumstances.

● *RECTIFIER CONTROL BY MAGNETIC AMPLIFIER*

For metallic rectifiers of the selenium type with less than 50 A charging capacity, a magnetic amplifier control has been developed which affords a plus or minus one per cent regulation of the voltage. The rectifier unit includes a line voltage regulator and a load regulator. The line voltage regulation system is of the ferro-resonant type. The load regulating circuit includes a saturable transformer with d.c. windings, so arranged that their fluxes oppose in the core and cancel each other at full load. A shunt d.c. winding is connected directly to the battery through a resistor network and relay contact, contributing a relatively constant amount of flux to the core. The series d.c. winding carries the load current and consequently contributes an increasing amount of flux to the core as the output current is increased to full load. With high saturation in the core, the impedance of the primary a.c. winding is fairly low and a certain proportion of the input voltage is developed across it, and, by transformer action, across the secondary. The a.c. voltage is rectified and applied to the battery and load. As the load current demand increases, the impedance of the primary increases in proportion to the losses in the system. At full load, the ampere turns of the two d.c. windings are equal and opposite and the consequent mutual cancellation of their fluxes results in maximum primary impedance. This, in turn, produces maximum voltage drop across the primary winding and maximum output vol-

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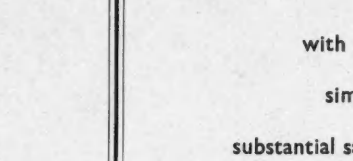

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tage. If, for any reason, the output current increases above full load, the series d.c. winding begins to re-saturate the core, thus lowering the impedance of the a.c. primary and causing the output voltage to decrease. This results eventually in fewer ampere turns in the d.c. shunt winding and tends further to saturate the core and further to reduce the output voltage.

● *STAINLESS CLAD COPPER SHEET*

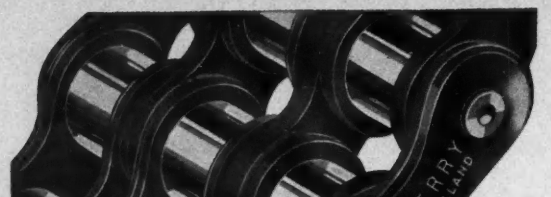
With few exceptions, stainless steels are the poorest heat conductors of all constructional metals, having about one-twentieth the thermal conductivity of copper and about one-third that of carbon steel. There are many cases, however, where the stainless qualities of the austenitic material should be combined with good lateral thermal conductivity. This applies, in particluar, to sheet material required for the fabrication of combustion chambers, tail cones, exhaust manifolds and similar parts where the heat impinging upon the sheet must be spread laterally in order to avoid the occurrence of hot spots, which would cause local deformation or cracking of the material. To a certain extent, the low thermal conductivity of the stainless material can be mitigated by using copper sheet clad with stainless steel sheet on one or both sides. In this material, the copper core, which usually is about 30 per cent of the total thickness of the clad sheet, serves to spread the heat away from the spot at which it strikes the sheet and also increases the heat conductivity as compared with a solid stainless sheet of equal thickness. In many cases it will be found that the high rate of lateral heat conduction results in a much greater heat transfer, because the heat conduction is spread over a much greater area. If protection of the copper exposed at the edges of the sheet is required, this can be effected by seal welding. Because of the comparatively low melting point of the copper (1981° F), the clad material should not be used for applications where the maximum operating temperature will exceed 1800° F.

● *TEMPERATURE MEASUREMENT OF ROTATING PARTS*

An interesting new method has been devised for transferring thermo-couple voltages from rotating members to standard temperature-indicating instruments. Instead of slip ring brush, slip ring compensation, or induction methods, a design has been evolved which permits continuous operation without the complication of controlled reference junctions. The design is based on transferring voltages through rolling contacts. Voltages from thermocouples on the rotating members are carried through lead wires to a slip ring type assembly, where they are transferred to spring-loaded wheels. Voltages are taken from the centre of the wheels by spring-loaded cone-shaped contacts. Two independent and continuous circuits are constructed by using chromel and alumel lead wires, contact rings and wheels, cone contacts, and connector plug contacts. A remote-controlled selector switch contained in the connector shaft was also devised. Two types have been developed; one that will permit the measurement of twelve thermocouples, one at a time, and a second switch which will handle twenty-eight thermocouples, two at a time. Thermocouple selection is accomplished by moving a pair of cone contacts longitudinally inside the cylinder formed by chromel-alumel ring segments, to which the thermocouple wires are soldered, to the desired pair of segments. The moving contacts, fastened to the actuating ring, are driven by a small d.c. motor through a gear train, traversing screw and follower yoke system. Location of the contacts in the shaft is determined by an impulse-type counter receiving a signal from a micro-switch for every revolution of the counter cam mounted on the traversing screw. A known number of revolutions will then correspond to a given ring position.

● *COMBATING DIAMOND WHEEL SHORTAGE*

Industrial diamonds are required in diamond-impregnated grinding wheels, diamond-tipped tools for truing and dressing grinding wheels, diamond-tipped turning tools, diamond drill bits, diamond dies for drawing fine wire, shaped diamond tools and many other purposes. Unfortunately, the demand for industrial diamonds greatly exceeds the supply and there exists an acute shortage of crushing bort, this being due to the limited world output which it is difficult to increase. Diamonds mounted in tools, wheel dressers, drilling bits, etc., are, however, never completely worn out and concentrated efforts should therefore be made to reclaim them. Also, diamonds can be salvaged in large quantity from the swarf and sludge of the diamond bearing grinding wheels and can be used in the manufacture of new ones. A method which serves to increase the cutting action of used diamond wheels utilizes a wire brush to remove some of the brass matrix of the wheel. This leaves the diamonds exposed for better cutting action, thereby increasing the service life of the wheel, it is claimed. In the brushing process, both the brush and the diamond wheel are rotated at high speed until a sufficient amount of the matrix forming the bond between the diamond particles is removed. It goes without saying that this treatment cannot be considered more than a mere stop-gap measure and the announcement just made by a British firm that a spark cutting process is being made available which is suitable for the cutting and grinding of hard metals, including carbides, would appear to be of considerable significance in view of the prevailing shortage of diamond wheels.



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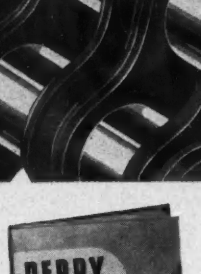

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● *FILM TYPE EVAPORATOR*

In evaporators for processing purposes, where the material in solution is sensitive to heat, it is highly desirable to hold it at the evaporating temperature as short a time as possible. In a film type evaporator a minimum of liquid is processed at a given time, because the volume represented by the film is small; hence, the evaporating time is greatly shortened. Vertical tube type evaporators, in which the film along the tube walls is freely formed by gravity effect, have been known for many years and, under average conditions, have proved very satisfactory in service. However, where highly viscous substances are to be dealt with, this evaporator type suffers from several shortcomings. Outstanding among these is the irregular film formation which leads to uneven evaporation. Moreover, in most cases, highly concentrated products cannot be obtained in a single pass so that recirculation must be resorted to, and this, of course, tends to lengthen process time. A novel type of film evaporator which was recently put on the market is claimed to avoid these shortcomings. In this apparatus evaporation takes place in a vertical tube equipped with a heating jacket, and the thin film is produced by an internal rapidly rotating stirrer. As the film is formed under the influence of centrifugal action, it is of uniform thickness and evaporation times as short as 15 seconds are claimed to be possible. The apparatus can be built for operation under vacuum. The feature that it incorporates rotating parts which must be driven from an externally arranged motor does not appear to affect its reliability or ease of operation.

● *HYDROGENATION BY ULTRASONICS*

Hydrogenation under pressure is difficult to carry out even under laboratory conditions, and the equipment required is highly complex. An outstanding difficulty in the realization of pressure-hydrogenation processes is that the pressure vessels required must be constructed of high-strength and corrosion-resistant steels. It goes without saying that this feature makes the capital cost of high-pressure hydrogenation plant very high. A novel hydrogenation method has now been devised which, according to the claims of its inventor, completely obviates the need for high-pressure plant as it does not involve the creation of outwardly perceptible pressures at all. The method relies upon the production of highly localized pressures in the substance to be treated by utilizing the phenomenon known as cavitation. It has been known for many years that cavitation, i.e., the sudden collapse of gas or vapour bubbles in a liquid, leads to the occurrence of enormous transient pressures. Thus, for instance, if the size of a steam bubble contained in water at atmospheric pressure is suddenly diminished to one-twentieth of the original size, a local pressure of 10,300 atmospheres will be generated in the immediate vicinity of the bubble surface, although no pressure rise will occur in the bubble surface proper. In order to produce cavitation, ultrasonic vibrations are passed through the substance to be treated. These vibrations produce cavitation pressures at the interface of the substance to be hydrogenated and the hydrogen; but as these pressures are strictly localized, no pressure vessel is required. It is reported that with an experimental installation equipped with an ultrasonic generator producing vibrations of 1,200,000 cps frequency, the hydrogenation of a number of substances has been successfully performed.

● *CONSTANT-COMPRESSION ENGINE*

One of the principal means of increasing thermal efficiency and producing greater power output in automotive engines is an increase in the compression ratio. Increased compression ratio, however, demands fuel of higher octane number, and such fuels are not only expensive but in much shorter supply than those of ordinary knock resistance. The advantage of an engine which can utilize fuels of lower grade is therefore obvious. Perhaps the most interesting proposal directed towards the use of lower octane fuels in high-compression engines is that relating to the employment of a constant-compression engine. It is well recognised that peak pressures and temperatures are lower during part-throttle operation of conventional Otto cycle engines. If, during these periods of light load, the volumetric compression ratio could be increased, the compression pressure would be higher. It is therefore conceivable that an automatically variable compression ratio engine could be proportioned and controlled in such a way that the compression pressure would remain substantially constant, regardless of the load. In the system recently tested, constant compression is maintained by the use of a variable piston mounted above the power cylinder and free to move in its control cylinder. The cavity of the control cylinder is supplied with lubricating oil from the crankcase of the engine by the lubricating pump. The oil pressure will maintain the control cylinder in its lowest position at low load, but if the throttle is opened fully, the increasing compression pressure will force oil out of the control cylinder through the relief valve set at the highest compression pressure chosen. When the pressure decreases, the control piston will again be forced down to decrease the clearance volume.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.

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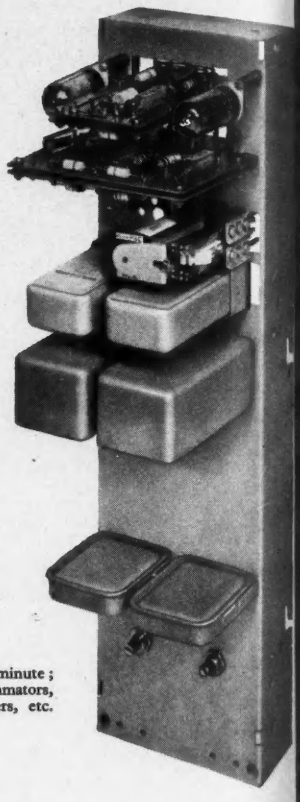

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THE ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XIII. No. 6. JUNE, 1952

Prediction of Hardenability

A patented method for determining in advance the hardening characteristics of steel compositions has been made available, free of cost, by the United States Steel Corporation to all American manufacturers of steel. As varying degrees of hardenability are indicative of the usefulness of steel for specific tasks, this knowledge will enable operating men to produce the types of steel which will exactly suit such diverse assignments as tough tank armour, strong struts for aircraft, brittle fragmentation bombs, or easily formable cases for shells.

Conversely, the patented method makes possible the design of steels of required hardening characteristics from the available supply of steel-making materials. Since many alloying elements normally used for special steels are now in short supply and others would be short if war were to block world sea-lanes, the new method will be of great assistance in making maximum use of existing supplies of traditional elements or of other elements that may be substituted to give approximately the same service.

In the past, it was roughly known which alloying elements improve the hardenability of steels. Now, by multiplying the hardening factors, we arrive at a closer approximation. This knowledge helps to rationalize and inject order in metallurgical planning.

In one column the hardenability required for a given job is set down. In a parallel column the quantities of available alloying elements are listed. With this information and the new data, steels of required hardenability can be designed by making use of available materials.

Recovery of Millions of Tons of Nickel Ores

The force of gravity has been put to work deep beneath the earth's surface in a vast mining programme which is helping to maintain the free world's supply of nickel. It has given mining science the key to recovery of millions of tons of nickel-copper ore once regarded as worthless.

Engineers of the International Nickel Company of Canada have recently adopted a mining technique by which gigantic masses of ore, far underground, are induced to cave and disintegrate under their own weight. The idea originated from observation of the natural tendency of the lower grade ore to subside and break up after higher grade ore beneath it has been mined out.

Called " induced caving," this low-cost bulk mining method makes it practicable to recover and treat ore lower in grade than it has ever been worked in underground mining, thus increasing the economically available supply of ore. In caving, a " slice " which may contain as much as 1,500,000 tons of ore is undercut. As ore from the undercut slice is withdrawn, the slice to be mined breaks away and starts to disintegrate as it moves downwards, the weight of the upper part of the mass acting to crush the ore at the bottom.

Another bulk mining technique, the " blast-hole " method, differs from caving only insofar as explosives are used to break the slices of harder, tougher ore from the solid material. The force of gravity then takes over, as in caving.

Terrae Rarae

The so-called rare earths, although largely ignored until 1945, when they were revealed as important in the development of atomic energy, are now not so rare and can be considered for new uses in industry. According to the Industrial Bulletin of Arthur D. Little Inc., these metallic elements together comprise nearly a fifth of all the known naturally occurring elements, yet constitute only about 0·005 per cent of the earth's crust. One of them, cerium, is more abundant than tin, silver, or gold, and several fairly rich deposits of rare-earth materials are known both in the United States and elsewhere.

The rare earths are all much alike chemically and hence difficult to purify, a fact which has retarded commercial development of all but a few of them. Recently, however, methods have been worked out for separating and purifying rare earths in solution by flowing the solutions through beds of " ion-exchange " resins, which adsorb the elements one after another as the solution progresses through the bed. This produces relatively small quantities of pure materials; commercial separation is done by fractional crystallization or solvent extraction. The rare earths were originally valuable in atomic research because the chemical methods for separating them could be used, with modification, in purifying the equally similar fissionable elements. Now they continue to be valuable because their atoms differ so little from each other that these small differences reveal new subtleties of atomic structure.

The increasing use of rare earths as ladle additions in stainless, tool, alloy and electrical steel production, constitutes a significant metallurgical development, many beneficial characteristics being imparted to steels thus treated.

Leak Detection with Radioactive Tracers and Halogen Gases in Gas Compression Cables and Pipes*

By N. KLEIN. (*Institute of Technology, Haifa*).

So far, leaks in buried gas compression cables have been detected and located with the help of large oxygen bubbles injected into the cable. This method is lengthy and not applicable to self-contained compression cables. New methods employing radioactive tracer gases, or halogen gases are described. These are also applicable to buried pipes and for determining the flow direction of very slowly moving gases.

1. INTRODUCTION.

Gas compression cables are used for the transmission of electrical energy at voltages exceeding 40-50 kV. These cables are compressed by nitrogen gas at 200 psi. The application of the gas pressure increases the electrical breakdown strength of the cable about five times. The cable is surrounded by a pipe, which is filled with the gas. There are two types of gas compression cables, the self-contained and the pipe-line type, shown schematically in Fig. 1. The three cores of the self-contained type are surrounded by a reinforced lead tube, having a narrow gap between the cores and the tube. The three cores of the pipe-line cable are surrounded by a large steel pipe.

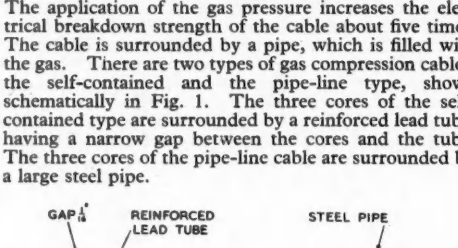

Fig. 1

The maintenance of the electrical breakdown strength of the compression cable requires the gas pressure to be kept at the prescribed value.

As cables are laid in the soil at a depth of 3 ft 6 in., the location of leaks is often very difficult without digging up the whole length. Several methods have been developed to find leaks in gas-pressure cables. These methods are based on the measurement of pressure differences or temperature differences, or on acoustic devices, automatic relays, etc. With the exception of pressure difference methods, however, they have not often been used in practice.

Leak detection has usually been carried out by means of injected oxygen or air bubbles. This method, which is due to O'Duffy[1], gave satisfactory results in the past, but has certain limitations. It is very time-consuming and cannot be applied to self-contained compression cables. New ways of leak detection were necessary and two methods have been worked out, i.e., leak detection with (a) radioactive tracers, and (b) halogen gases. They are suitable not only for use in compression cables, but also for leak detection in buried pipes and for the determination of gas flow at very low velocities.

For a better understanding of these new methods it is advantageous to show first how leak detection is carried out with large gas bubbles.

2. O'DUFFY'S METHOD OF LEAK DETECTION WITH GAS BUBBLES.

Cables are made in lengths of a few hundred yards. When the cables are laid in the ground their ends are connected by joints. The cable is covered by soil, but the joints are usually easily accessible through joint-holes. This makes possible the first step in the detection of leaks by the method of elimination.

Fig. 2 shows schematically a cable laid in the ground, the joints being numbered ; *A* and *B* are the terminals. If there is a leak in the cable pipe at the point marked *L*, the gas flows towards it both from left and right. By determining the flow direction at individual joints along the cable the leaking section can be ascertained. The first determination is carried out at the middle joint No.5, the next at joint No. 8, both joints indicating flow to the right. A further flow determination at joint No. 9 indicates flow to the left ; therefore, the leak is located in the cable section between the joints 8 and 9.

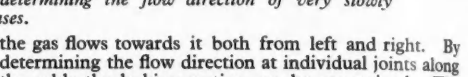

Fig. 2

To find the direction of flow in a joint, O'Duffy injected into the joint an oxygen or air bubble, which started to flow towards the leak. If the bubble was injected into joint No. 5, it arrived after a certain time at a point *C*. The bubble was then gradually pushed back to joint No. 5 by injecting a certain quantity of nitrogen at terminal *B*, while the same quantity was extracted at terminal *A*. The gas in the cable pipe was analysed at joint No. 5 after every push. If, after a certain number of pushes, increasing oxygen content was found in the gas, it became clear that the bubble flowed towards the right and the leak was also to the right. Of course, if the bubble were pushed in the opposite direction first, it could not be traced.

The location of the leak between joints Nos. 8 and 9 does not mean completion of the operation, because the distance from point 8 to point 9 is a few hundred yards long and it is very costly to dig up such a cable section. According to O'Duffy, an oxygen or air bubble is again injected into joint 8 or 9. It flows towards the leak for a certain time, after which it is pushed back to the injected joint and analyzed for its oxygen content. If the shape of the bubble is as shown in Fig. 3a, the bubble did not flow as far as the leak ; if, however, it turns out to be as in Fig. 3b, it reached the leak. From the time the bubble took to flow towards the leak and from the speed (known from the size of the leak), the position of the leak can be calculated.

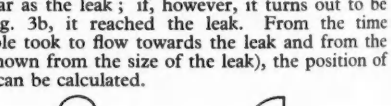

Fig. 3

Such leaks could be located within an accuracy of about 10 yards and the determinations were successful when the quantity of leaking gas exceeded 50 cu. ft/day at NPT. When the leak was smaller, diffusion of the gas bubble became very disturbing.

By fundamental consideration of the nature of bubble diffusion and bubble pushing, this method can be considerably improved. It seems to be advisable to inject much smaller bubbles than usual. By changes in technique it is expected that the time taken for direction finding in the joints could be reduced to about one hour and leaks much smaller than 50 cu. ft/day at NPT detected. While the determination of flow direction would be possible in this way in self-contained compression cables, the exact location between two joints could not be effected with an oxygen bubble.

* Published concurrently in *Scientific Publications of the Hebrew Institute of Technology*, Vol. 5, No. 1, 1952.

3. LEAK LOCATION WITH RADIOACTIVE TRACERS.

It was thought that the difficulties and limitations of the method of leak location by a gas bubble could be overcome by the use of radioactive tracers, which can be detected above the point of leakage. While this method could not be carried out easily, another tracer method allows quick determination of the flow direction in joints.

FLOW DIRECTION FINDING WITH RADIOACTIVE TRACERS.

Flow direction finding with radioactive tracers was again carried out by injecting a bubble into the joint. The bubble had to be radioactive and its movement was observed by a suitable instrument.

It was not clear at the beginning of the experiments of what material the tracer should be, because of the following limitations :

(a) The quantity of tracer should not endanger the health of the attending personnel.
(b) The tracer should be available immediately, when a leak occurs in a cable.
(c) The quantity of tracer used in the cable should not damage the insulation.
(d) The tracer should not react chemically with the lead, copper, oiled paper and hessian of the cable.
(e) The tracer should not become absorbed strongly by the lead, copper, oiled paper and hessian.
(f) The tracer should preferably be gaseous.
(g) The half-life of the tracer should be of the order of a few days.
(h) The tracer should emit γ-radiation of sufficient energy to make it detectable across the wall of the joint armature.

It was difficult at first to obtain radioactive gases, because only solid and not very volatile liquid compounds were accepted for activation by the Atomic Energy Research Establishment at Harwell. To overcome this difficulty, the following method for the preparation of a radioactive gas-mixture was devised.

A volatile liquid compound, the vapour-pressure of which at ambient temperatures is a fairly large fraction of the atmospheric pressure, is selected for activation. The activated liquid is introduced into a sufficiently large vessel and evaporates there, thus forming the radioactive gas mixture with the air in the vessel.

It was thought that an organic bromine compound would be suitable as a tracer material. The half-life of the Br^{82} isotope is 34 hours, emitting β-radiation of 0·465 keV and γ-radiation of 0·55, 0·79 and 1·35 keV energy. Bromine compounds are quickly activated, e.g., one gram of the salt NH_4Br can be irradiated to an activity of 22 mc* in less than a week. As the total activity of the tracer gas required for leak detection is about a thousand times less, the irradiation time is very short and the tracer material is quickly obtainable.

The first experiments were made with n-propyl-bromide, which boils at 70·9° C. This compound evaporated in the bottle used for injection in the described manner; contrary to expectation, however, the radioactivity of the tracer injected into the joint was not sufficient to allow easy leak detection. The reason was that the compound changes chemically during the activation in the atomic pile, due to the Szilard-Chalmers reaction. Active bromine forms, but hardly any active n-propyl bromide. The active bromine reacts with the metal wall of the injection bottle and only very little radioactivity is left in the tracer gas. Most liquid organic bromine compounds behave similarly.

It has been decided, therefore, to activate the salt NH_4Br, which is a solid, and to produce from it chemically a radioactive liquid. Ethyl bromide, C_2H_5Br, was made by introducing ammonium bromide into a mixture of sulphuric acid and alcohol and distilling the ethyl bromide thus formed. The weight and activity of the radioactive C_2H_5Br produced in this way were roughly one third of those of the activated NH_4Br.

The radioactive ethyl bromide proved to be a suitable tracer material. The boiling point of C_2H_5Br is 38·4° C at NP and the vapour pressure is a large fraction of the atmospheric pressure at ambient temperatures. Comparatively large quantities of this material could therefore be evaporated in the injection bottle. This compound hardly reacts chemically with the different materials in the cable, and the absorption by these materials is not large enough to cause difficulties in the determination of the flow direction.

Experiments with this tracer gas were carried out on a 66-kV, 0·25 sq. in., single-core self-contained compression cable. There were four joints in the cable; bubbles could be injected into one of the middle joints and the cable terminals and leaks could be made at the same points.

The method worked out for flow direction finding in these experiments consists of the preparation and evaporation of the activated ethyl bromide in the injection bottle first. The injection bottle is small, its inside volume being 0·1 cu ft. Gas from the injection bottle cannot be injected at once into the cable after the evaporation of the C_2H_5Br, because the pressure in the cable is higher, of the order of 200 psi. The injection bottle is therefore filled with nitrogen to a pressure of 400 psi, which mixes thoroughly with the tracer during filling. It is then simple to inject a tracer bubble into the joint. Usually, sufficient tracer gas has been pressed into the joint when the pressure in the injection bottle drops by 5-20 psi. This corresponds to a bubble volume of 0·03 to 0·13 cu ft at NPT and the cable joint, according to its size, is more or less filled with the tracer gas. The injection of bubbles from the bottle can be carried on until the pressure in the bottle drops to that of the cable. Many bubbles can thus be injected from a relatively small bottle.

Part of the injected C_2H_5Br becomes absorbed by the inside materials of the joint, as can be observed after the bubble flows away towards the leak. This is not a disturbing factor, because the injected bubble contains more C_2H_5Br than is absorbed during the time taken for determining the flow direction.

The flow direction is found with instruments for the detection of radioactivity, of which there are several kinds. Those chosen were Geiger-Müller counters, which are sensitive to γ-radiation. Most of the γ-radiation passes through the wall of the cable armature, the losses according to wall thickness and material being

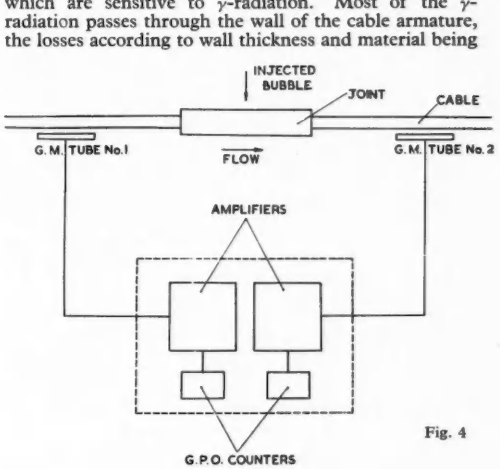

Fig. 4

*The radioactivity of a substance is usually given in curies, 1 c being the activity, when $3{\cdot}7 \times 10^{10}$ disintegrations per second occur in it. Smaller units are 0·001 c = 1 mc (millicurie) and 0·000001 c = 1μc (microcurie).

of the order of 10-20 per cent. Two G.M. tubes are used and placed on either side of the joint at a distance of 1-2 feet (see Fig. 4). Pulses due to the ionization by the different types of radioactive radiation pass through the G.M. tube. Before a bubble arrives at a G.M. tube, a fairly steady number of pulses due to cosmic radiation and terrestrial radioactivity are counted. This is called the background of the tube. When a bubble arrives at one of the tubes (in Fig. 4 at tube No. 2), the number of pulses in that tube increases above the background counts and the flow direction is detected.

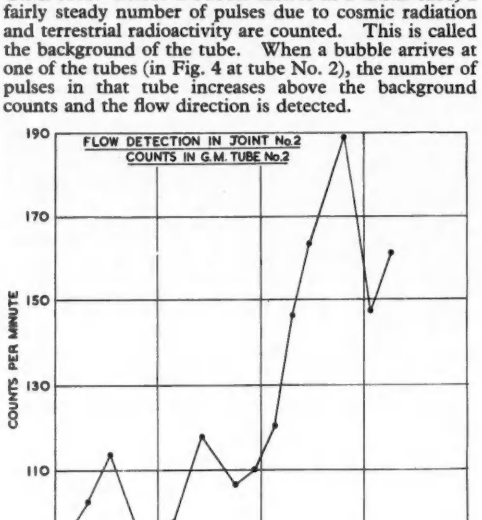

Fig. 5

Fig. 5 shows an example of flow direction finding according to this method. It can be seen that the number of pulses was approximately 100/min in a G.M. tube in the first 10 minutes after the injection of the bubble corresponding to the background counts of the tube. In the following minutes, the number of counts increased to 190/min due to the arrival of the pulse. At the same time there was no rise in the average number of pulses in the second G.M. tube.

Very small flow speeds corresponding to very small leaks can be detected by this method, e.g., flow speeds of a few inches per hour. Larger activity of the tracer gas is, of course, necessary in such cases in order to increase the sensitivity and counteract the effects of absorption and diffusion. Flow direction determinations for 10 cu ft/day leaks at NPT were carried out; this, however, should not be the lower limit of the method.

The G.M. tubes for the detection should preferably be small. Those used in the experiments were 4 in. long and $\frac{3}{4}$ in. in diameter; they were of the self-quenching type, filled with an argon-alcohol mixture. Copper cathodes were used in the first experiments and the background counts were about 45/min. The efficiency of these G.M. tubes is very low and probably less than 1 per cent of the γ-photons emitted by the active ethyl bromide was recorded. The counting efficiency of the tubes is somewhat better when the cathode is made of lead, but the background counts increase to about 70/min for the same size of tube. The question of the efficiency of the G.M. tubes is not very important, because the flow detection is simple, even when the activity of the tracer gas is very small.

Several methods were tried for counting pulses. The counting of the pulses in Fig. 5 was carried out by an electronic two-stage amplifier, in which the signals coming from the G.M. tube are transformed into equal-sized pulses in a metastable multi-vibrator circuit. These pulses acted on an electro-mechanical, digital counter of the type used by the General Post Office. The apparatus incorporated amplifiers and counters for both tubes and was connected to the 230 V a.c. mains, and the voltages on the G.M. tubes varied between 1000-1350 V.

The counting apparatus has to be different when used for leak detection in the field, because it is battery-fed. It appears that halogen gas-filled tubes are of great advantage for such an apparatus, because they work at a voltage of about 350 V.

The magnitude of radioactivity of the tracer gas is, of course, of prime importance for leak detection. The radioactivity necessary for the tracer material was determined by approximate calculations, taking into account the joint, cable and G.M. tube dimensions, the number of bubbles required, the different losses in activity, the efficiency of the G.M. tubes, etc. (see Appendix). On this basis, the experiments were carried out with tracer materials varying in weight between 1 and 50 g and in activity between 1 and 50 μc. These weights and activities of the tracer gave satisfactory results; also, the health hazards incurred and the damage to the insulation are completely negligible. This is shown in the following:

The γ-ray dose received[2] per hour at a distance of one foot from one millicurie Br^{82} is 16·1 mr (milli-roentgen)†. The total activity of the ammonium bromide required for leak detection is about 0·02 mc. Assuming the person using the tracer is, in the worst case, one foot away from it for ten hours, the γ-ray dose he will receive is $0{\cdot}02 \times 10 \times 16{\cdot}1 = 3{\cdot}2$ mr. According to the British Medical Research Council, the maximum permissible exposure to X-or γ-radiation is 500 mr per week. Thus, the safety of the tracer leak detection is larger than 100.

Similarly, the insulation is safe from any practical damage by the tracer material. This would be expected from fundamental considerations. The activity of the tracer material is very small. The number of disintegrations in one of the experiments was about 1400/sec per inch length of cable, or about 4×10^{-6} mc per inch, which corresponds to an irradiation of about

$$\frac{16{\cdot}1 \times 48^2 \times 4 \times 10^{-6}}{60} = 2{\cdot}5 \times 10^{-3} \text{ mr/min, inch}$$

at a distance of $\frac{1}{4}$ in.

Numerous experiments were made on the change of conductivity of semi-conductors by the action of radioactive irradiation[3, 4] and some are indicative of the probable behaviour of oil-impregnated paper insulation under such circumstances. Thus, Armistead, Pennock and Nead[5] showed that the conductivity of polyvinyl chloride increased 30 times during irradiation by 2·5 MeV X-rays, at a rate of 400 r/min. The polyvinyl-chloride recovered nine-tenths of its original resistivity 16 hours after the irradiation. Comparing the effect of this 400 r/min source with the $2{\cdot}5 \times 10^{-6}$ r/min/inch irradiation of the tracer material in the cable, a noticeable effect of the tracer on the insulation is very improbable.

Thus, this method of flow direction finding in compression cables is not only efficient, but also safe.

In the same way as flow direction finding is carried out in gas-compression cables, the flow in tubes can be found with tracers.

Leak detection with radioactive tracers between joints.

With radioactive tracers, the determination of flow direction in joints is carried out by the same method of elimination as with oxygen bubbles.

†1 roentgen is the intensity obtained from that radiation, which at NPT produces in 1 cm³ of air such a degree of conductivity that the quantity of electricity measured at saturation current equals one electrostatic unit.

However, the finding of the exact position between the two joints is attempted by different methods. The gas space of the cable between the two joints is filled with a radioactive tracer and the aim is to detect the escaping tracer above the point of leakage at the surface of the soil.

For the purpose of the experiments, a pipe was buried at a depth of 3 ft 6 in. in the soil. In one of the tests, nitrogen gas leaked from the pipe at a rate of 37 cu ft/day at NPT. 50 grams of ethyl bromide of an estimated radioactivity of 10 μc were mixed with the N_2. A detector consisting of six G.M. tubes, which were each 65 cm long and 37 mm in dia., was placed above the point of leakage. The pulses in the G.M. tubes were amplified electronically and indicated on an ammeter. An opposing current was applied to ensure that the ammeter should not indicate large background counts of the G.M. tubes.

In spite of the large size of the detector, no appreciable indication was shown by the ammeter as a result of the leak. Digging of the soil therefore was started and the ammeter began to indicate from a depth two-thirds that of the leak. After the soil had been dug to the point of the leak, counting with a G.M. tube of 115 mm cathode length and 22 mm dia. was carried out at different heights in the pit. The background counts of the tube were subtracted from the counts thus obtained and were plotted, as in Fig. 6, against depth below surface.

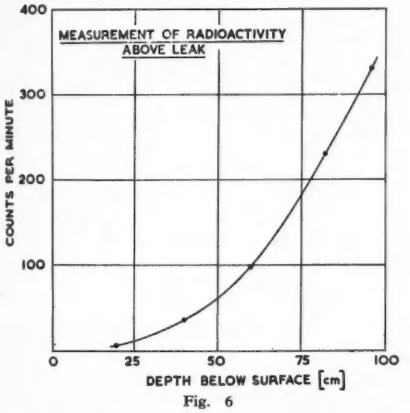

Fig. 6

It transpired from these measurements that most of the ethyl bromide was absorbed by the wet soil around the leak and therefore could not be detected at the surface. This is understandable because the solubility of C_2H_5Br is 0·91 g in 100 g of water at 20° C. It follows that large quantities of ethyl bromide would have to leak into the soil before it begins to saturate the surface soil layer, and become detectable if radioactive. The use of the C_2H_5Br for the purpose of radioactive tracer detection is therefore impracticable.

The gas which would make radioactive tracer methods possible should be absorbed as little as possible by the soil. Such a gas is, e.g., dichlorodifluoromethane, which is used also in halogen gas leak detection (see below). The radioactive tracer element in this gas would be C^{14}, which emits 0·145 MeV β-rays and has a half-life of more than 1000 years. The difficulty in using this material for the leak detection is, however, considerable and is related to the method of its activation.

Assuming that it were possible to find a suitable tracer which is not absorbed by the soil, it has to be realized that the method of radioactive leak location between two joints is beset by further difficulties. The activity required for the tracer in this method can be estimated from the gas space between the two joints, the extent of the leak, the sensitivity and size of the detecting instruments, etc. Such estimates result in high activities necessary for the exact location of the leak position, which are much higher than those needed for the flow direction determination. To reduce health hazards, maximum sensitivity of the γ-ray detecting instruments is important, which is obtained by increasing the pressure in the G.M. tubes or by choosing cathode materials of high molecular weight. G.M. tube counters might be replaced in this case by scintillation counters, which have an efficiency of 15 per cent for γ-ray counting. They were recently used with great success in the mapping of soil radioactivity[6]. A further step towards decreasing the necessary radioactivity would be to use a tracer, the β-radiation of which is observed, because counts are caused by almost every electron passing through the G.M. tube.

The difficulties seem much greater when the whole cable is to be filled with a radioactive tracer and the leak has to be found by following the cable trench with the detector. These are due to the fact that the entire gas content of the cable has to be renewed and mixed with a tracer of very high radioactivity.

4. LEAK LOCATION WITH HALOGEN GASES.

While radioactive tracers make leak location between two joints comparatively easy, a further method was necessary for the determination of the exact position. To this end, halogen gases were used.

An instrument, based on observations of C. W. Rice, has recently been developed by W. C. White and J. S. Hickey, namely, the halogen gas leak detector[7,8] which is extremely sensitive to the presence of certain gaseous compounds containing halogen elements; this instrument detects them at a concentration of one part in a million. It draws the gas to be tested with the aid of a small fan into a special diode with platinum electrodes. The anode of the valve is heated to a temperature of about 800° C. If halogen-containing gas is drawn into the valve, it is thought that high positive ion emission starts at the anode, causing a large valve current, which is amplified, producing a deflection on an ammeter and also a wailing sound from a loudspeaker.

The instrument consists of two parts, the detector in the shape of a pistol, incorporating the diode, the fan and the loudspeaker, and the amplifier with the ammeters in a separate casing. The gas is drawn through a narrow pipe into the diode.

This instrument has been used for detecting leaks above the soil. The tracer gas chosen was dichlorodifluoromethane, CCl_2F_2 (commercially known as Freon 12, or Arcton 6), which is practically insoluble in water. At ambient temperatures, CCl_2F_2 is a gas; it liquefies at a pressure of about 75 psi and is supplied in a liquid state.

Experiments were carried out first with two steel pipes, which were buried at a depth of 3 ft 6 in. One pipe was buried in heavy soil, the other in light soil. The pipes were fed with gaseous CCl_2F_2 from a bottle as shown in Fig. 7. The gas leaked away at the ends of the pipes, flowing towards the surface along flow lines which are schematically shown in Fig. 7. The experiments show that the CCl_2F_2 quickly reaches the surface.

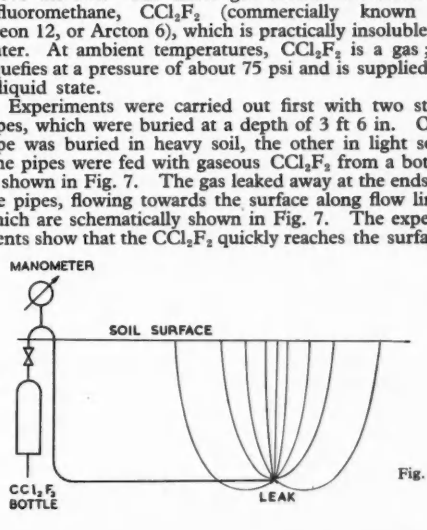

Fig. 7

It was found on different occasions that the halogen gas detectors indicated the presence of the gas 5 to 15 minutes after the start of the leak. The indications increased in magnitude for 30-60 min, after which they remained constant. The rate of flow of the CCl_2F_2 can be calculated from the known values of flow resistance of the soil. Accordingly, very soon after the start of the leak, full flow should appear at the soil surface. As this is not the case, it has to be assumed that some CCl_2F_2 is absorbed by the soil. This can be verified by the large indications which occur when small grains of the soil are accidentally drawn into the diode.

The gas could be detected with the leak detector at the surface in the case of leaks of the order of 150 cu ft/day at NPT. The detection became easier when the gas escaping through the surface was collected under covers.

The standard method, however, was to drill holes of 1-3 in. depth and test in them for the tracer gas. There are sufficient concentrations of gas in such holes, and leaks of a magnitude of 10 cu ft/day at NPT were easily detected.

The concentration of the gas is the largest above the point of leak and then falls off as shown in Fig. 8. It has been found that in the case of the leak of 170 cu ft/day at NPT, the gas could be detected in the holes at a maximum distance of 8 ft from the point of highest concentration.

Fig. 8

Only when it rained was it difficult to detect the leaking gas with the halogen gas detector, because the pores of the soil were filled with water and the leaking gas could not reach the surface. Very soon after the rain ceases, detection again becomes possible.

The detection of a leak with halogen gases between two joints is carried out by filling the gas space with a mixture of CCl_2F_2 and N_2 and by searching for the escaping gas with the halogen gas detector along the cable trench.

A further possibility is to fill the gas space of the whole cable with the above mixture and to search for the leak along the trench from one terminal to the other. This method of leak detection might be difficult if the position of the cable trench is not exactly known. The cost of filling the cable with the tracer gas is also considerable. A compression cable recently laid, however, was filled with such a gas mixture. This arrangement had the advantage of making it possible to detect leaks due to faulty fitting of the joints or of the terminals.

It should finally be mentioned that Freon could also be used for the detection of flow direction in joints. In this case, the joint would need to have three plugged holes, one for the injection of the CCl_2F_2 and two for sample-taking.

Other halogen gases, such as SF_6 or CF_4, could also be used for detection. In every case, however, the gas absorption qualities of the soil, the sensitivity of the detector to the gas, the vapour pressure, its inert qualities and economic factors have to be considered.

5. CONCLUSION.

The methods which have been developed for leak detection in compression cables can be used in different ways. It seems that in many cases the combination of flow direction finding with radioactive tracers and halogen gas detection between joints might produce results in the quickest and cheapest manner. Alternatively, the cable might be filled after laying with a mixture containing a halogen gas. In this case, leak detection requires only the use of the halogen gas detector along the cable trench. Similar considerations apply to leak detection in buried pipes. For the determination of very slow movements of gases, radioactive tracers are advantageous.

APPENDIX.

THE ACTIVITY OF A TRACER GAS.

An estimate of the activity of the tracer gas necessary for flow direction determination can be made in the following manner.

If the increase of the number of pulses in the counter is p per min, then the number of radioactive disintegrations in unit length of cable opposite the G.M. tube per sec is $p/(60\,l\,f\,\epsilon\,\lambda)$ where ϵ is the efficiency of the pulse production in the G.M. tube and is about 0·01 for Br^{82} γ-ray photons; λ is the fraction of the radiation transmitted through the cable sheath, and its value is between 0·8 and 0·9; l is the electrode length of the tube and f a form factor for that part of the radiation from the cable which reaches the tube, and its magnitude is of the order of 0·05.

If the length of the injected bubble is L, the activity of the gas injected into the joint should be $\dfrac{p\,L}{60\,l\,f\,\epsilon\,\lambda\,\sigma}$ where σ is the ratio of the available tracer gas to the total injected (part of which becomes absorbed).

There is gas for n bubbles in the injection bottle and the total activity in the bottle is therefore n times the above expression.

As mentioned before, only a fraction η of the required activity of the NH_4Br is obtained in the ethyl bromide: therefore, the activity of the BH_4Br at the time of application of the tracer gas should be, in micro-curies

$$\frac{p\,n\,L}{60\,l\,f\,\epsilon\,\lambda\,\sigma\,\eta} \times \frac{1}{37000}$$

The activity of the NH_4Br should be greater at the end of the irradiation by the factor $e^{t/\tau}$, or

$$\frac{p\,n\,L}{60\,l\,f\,\epsilon\,\lambda\,\sigma\,\eta} \times \frac{e^{t/\tau}}{37000}$$

t is the time which elapses between the ending of the irradiation and application of the tracer in the cable, and 0·693 τ is the half-life of radioactive bromine.

Replacing representative values in this formula: $p = 100$/min, $n = 20$, $L = 12$ in., $\epsilon = 0{\cdot}01$, $\lambda = 0{\cdot}9$, $\eta = 0{\cdot}33$, $l = 4$ in., $f = 0{\cdot}05$, $\sigma = 0{\cdot}5$, $e^{t/\tau} = 2$, the radioactivity required after the irradiation is 72 μc.

The weight of the ammonium bromide which should be activated follows from the weight of the vapour of C_2H_5Br, which saturates the volume V of the injection bottle at ambient temperature. The weight of this vapour is 0·00486 × 386 V/760 where 0·00486 gram is the specific gravity of the vapour at NPT, 386 mm Hg is the vapour pressure of C_2H_5Br at 20° C, and 760 mm Hg is the normal atmospheric pressure. The weight of NH_4Br which is activated is at least three times the above value, or 0·0075 V, because only part of the bromine of the NH_4Br is recovered in the C_2H_5Br produced.

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Liquid Metals as Heat-Transfer Agents

By TH. TROCKI. (From *General Electric Review*, Vol. 55, No. 3, May 1952, pp. 22-25, 60, 3 illustrations.)

LIQUID metals have singular advantages as heat-transfer agents for certain high-temperature applications in our modern industrial economy. Water, although an excellent heat-transfer fluid and the most widely used medium for this purpose, has certain disadvantages above 500° F. These include high vapour pressure and a tendency to break down into hydrogen and oxygen. Metals, however, have much higher boiling points and consequently negligible vapour pressure at those temperatures. Furthermore, their very high thermal conductivity yields higher heat-transfer coefficients.

Apart from mercury power plants, no applications of any consequence have yet been made. Possibilities include the use of liquid metals as coupling fluids in power and process applications, such as steam reheating, regenerative heat exchangers for gas turbines, and chemical processes requiring uniform heating and cooling. Liquid metals also appear to be particularly suitable as coolants for high-temperature nuclear reactors.

From a practical standpoint, liquid metals offer the following advantages :

1. A high boiling point means less likelihood of localised boiling and over-heating ; lower fluid pressure produces lower stresses in tube walls.
2. High heat-transfer rates result in cooler tube walls, longer tube life, and more uniform cooling and heating.
3. Thermal and chemical stability permits the use of higher operating temperatures.
4. Liquid metals do not decompose when subjected to nuclear radiation, although they would become radioactive in passing through a reactor.

Liquid metals have a disadvantage in their relatively low heat-storage capacity. A larger quantity of liquid metal than of water is needed to remove a given quantity of heat. But this is not a serious limitation to their use.

HANDLING PROBLEMS.

The main problems in handling liquid metals stem from their corrosion of structural materials and their chemical activity or toxicity at the high temperatures involved.

Compared with ordinary materials in general industrial use, the liquid metals are relatively difficult to handle—but this is an unfair comparison ; for the handling of any fluid at high temperature is hazardous to personnel, and the precautions required for handling it safely go a long way toward reducing the chemical activity or toxicity hazard. Thus, the handling of liquid metals should more properly be compared to the handling of high-pressure high-temperature steam in modern power plants, or to active chemicals in many chemical processes.

The basis for the successful handling of chemically active or personally hazardous materials is to contain them in an inert atmosphere and prevent leakage. The chemical and power industries have pioneered in the development of adequate techniques for the design, construction, inspection, and pretesting of piping and equipment. These techniques are applicable to systems for handling liquid metals, with some minor provisions for the unique requirements of the latter.

Obviously, the success of any such system depends on the use of a structural material which will not be corroded by the contained liquid metal. It is, therefore, fortunate that many of the high-temperature structural materials are compatible with liquid metals as long as proper precautions are taken to purify the liquid metals initially and keep them clean.

Oxygen appears to be the principal contaminant affecting corrosion, and it must be kept to a minimum. This requirement, however, is not restricted to liquid metals.

Oxygen solubility in liquid metals is also temperature-dependent, and this is used as the basis for oxygen removal. " Getters " have also been investigated for liquid metals, but their effectiveness has not been established.

It can be seen from the foregoing that leak-tightness is the most important single requirement for a liquid-metal system. The difficulties resulting from leakage of liquid metal in such a system vary with the liquid metal concerned. Some of the metals—such as lithium, sodium, and potassium—burn in air ; others—such as lead and mercury—are toxic. And any material at high temperature will burn flesh.

Leakage of air into the system results in contamination of the liquid metals, and this increases their corrosiveness.

Broadly speaking, the development leading to the successful handling of liquid metals has been devoted, first, to gaining an understanding of the limits and control of liquid-metal contamination, with the object of controlling corrosion ; and, second, to developing leakproof heat exchangers, pumps, valves, and system auxiliaries.

HEAT EXCHANGERS.

Flanged joints and the joints formed by tubes rolled into tube sheets, commonly used in heat exchangers, do not appear satisfactory for containing liquid metals at high temperature. For this reason, the liquid-metal circuit of a heat exchanger is completely welded. However, on the steam or air circuits, where there is little possibility of contact with liquid metal, conventional practice is acceptable.

The chemical reactivity of the alkali metals—lithium, sodium, and potassium—with water requires more than usual precautions to prevent their mixing. For extra safety in a liquid-metal-heated steam generator, concentric independent tubes are used, welded into separate headers. The annulus between the tubes is filled with mercury, to provide a good heat-transfer bond and permit differential expansion.

The high heat-transfer coefficients of liquid metals have an interesting effect in the design of heat exchangers. In conventional heat exchangers, the heat-transfer resistance of the fluid films is usually a controlling factor in the over-all resistance of a heat-exchanger wall. Liquid metal heat-transfer coefficients are comparatively high ; hence, their equivalent film resistances are low, and they usually constitute a minor part of the total resistance. In a liquid-metal-to-liquid-metal heat exchanger, both film resistances are low ; hence, the wall resistance becomes the major factor in determining the heat-transfer rate. Economy of surface can be effected by reducing this resistance through the use of thin walls of high-conductivity material. The comparatively low working pressure of liquid metals at high temperature permits the use of thin-walled tubes. The lower limit in wall thickness is, of course, determined by fabrication difficulties.

Because the major part of the total temperature drop occurs across the tube wall rather than in the fluid film, thermal stresses in the tube wall become significant, and the total temperature drop for a heat exchanger must be selected with this fact in mind. Steady-state thermal stress in a tube is directly proportional to the temperature difference across the wall. There is only very limited experience available today, from which values of allowable design stress for thermal stress can be selected. Some arbitrary limits have been assumed that permit the use of stresses beyond the elastic limit of the material

at the temperature involved, on the basis that plastic flow of the metal occurs. Much work needs to be done to advance our understanding in this field similarly to that of design by elastic theory.

Heat exchangers transferring heat from sodium to sodium-potassium and steam generators using sodium-potassium as the heating fluid have been built and operated successfully in a pilot plant of considerable size. No particular difficulty has been encountered in operation up to a maximum temperature of 1000° F, and the measured performance checked with predicted performance at the design point. A significant discrepancy in performance was noted at partial-load conditions.

PUMPS AND VALVES.

In the liquid state, the light metals have fluid properties similar to those of water or alcohol. The hydraulics of pumping liquid metals is not much different from that of pumping the more common fluids. The problems in pumping liquid metals arise from the elevated temperatures of the applications and the necessity of absolutely preventing metal leakage out or air leakage in.

The no-leakage requirement practically eliminates a stuffing box or mechanical seal for the liquid metal.

Improved designs of mechanical pumps have solved the seal problem by using a submerged-rotor type of construction. In this design, the pump impeller, shaft, and motor rotor are all submerged in the fluid, with the seal consisting of a thin diaphragm in the motor air gap. The main problems introduced by this construction involve the operation of bearings in the liquid metal and the cooling of the motor. Several designs of this type have been built and operated.

As in pumps, the main special requirement for valves in a liquid-metal system is leak-tightness to the atmosphere. It is understood, of course, that it is desirable to hold leakage across the seat to a minimum as is done with any valve. Packing around the stem is not considered satisfactory for liquid metal use. Bellows-sealed—so-called packless—valves have proved quite satisfactory. In these, the bellows are welded to the valve disc and valve body, forming a complete and continuous metal seal. There have been some bellows failures, but the percentage of these has been reasonably small, and the leaks were detected without damage or injury.

The metallic properties of liquid metals open the door to a very interesting possibility—pumping by direct action of electromagnetic forces. The motive force in the several basic types of motor design can be directed to act on the liquid metal instead of on the armature conductors. Pumps similar in principle to d.c. and a.c. motors have been built and operated. The performance of such units can be predicted on the basis of motor calculations adjusted to account for a continuous fluid conductor instead of for separate solid bars or wires.

A.c. units of both conduction and induction types have been built. The former are similar to d.c. pumps in construction. Small units using transformer action to provide the large armature currents are commercially available and are in common use in several laboratories engaged in liquid-metal development work. Although they are relatively inefficient, they are convenient because they can be plugged into a standard mains supply.

INSTRUMENTATION.

The metallic properties of the liquid metals also lend themselves readily to measurement by electromagnetic means. An accurate flow measurement can be taken by measuring the e.m.f. generated by liquid metal flowing in a magnetic field. A singular advantage of this method of measurement is that it can be installed outside the piping.

Measurement of liquid level can be made by measuring the effect of the liquid metal on the inductance of a coil immersed in it. Level can also be determined by measuring the resistance of a wire immersed in direct contact with the metal and short-circuited by it to the depth of immersion.

Pressure measurements are somewhat more difficult. An indirect method measures the pressure of inert gas over the liquid metal; another uses a sealed pressure transmitter, in which a balance of pressure is maintained across a diaphragm. The balancing pressure is measured, and this gives an accurate indication of the liquid-metal pressure.

PIPING AND AUXILIARIES.

The need for leak-tightness also affects the piping and vessels, but to a lesser degree. It has led to the development of adequate fabrication and inspection techniques to assure soundness.

One problem results from the low design pressure of liquid-metal systems and also from the ability of liquid metal to leak through extremely small cracks. The hydrostatic test pressure for a high-pressure power plant will locate practically all flaws that may leak steam. The low design pressure of liquid-metal systems limits the hydrostatic test pressure to a nominal value, and leaks that later may leak liquid metal can go undetected.

A more sensitive low-pressure leak test is therefore desirable. Either the helium mass-spectrometer leak tester, used in testing vessels made for vacuum use, or the halogen-type leak detectors now used in locating leaks in refrigerator unit assemblies, is applicable to this service, and liquid-metal piping systems leak-tested by these methods are usually satisfactory. The leaks that are not detected by these tests are not dangerous; they can be detected without difficulty after the liquid metal has leaked. With care, small leaks can usually be detected and repaired without affecting the system.

Other requirements for a liquid-metal system not usually encountered in piping systems are pipe heating and the need for an inert-gas blanket over the free surfaces of the liquid metal. Because many of the liquid metals are solid at room temperature, provision must be made to preheat all parts of the system before filling and to thaw out a system if the metal should solidify in it. The heating is most easily done by winding the pipes with a resistance heating wire of low heating intensity designed for this purpose. High-intensity heaters are used in special places, but they present the danger of overheating on an empty well-insulated pipe. The heating wire is armoured with a woven wire mesh for ease in handling and installation.

The inert gas is provided to blanket the free liquid-metal surfaces and to maintain system pressure above atmospheric at all times, thus preventing air leakage into the system. It is desirable to supercharge the system, in order to keep all parts above atmospheric pressure at all times.

LIQUID-METAL PURIFICATION.

It has been determined from metallurgical tests and considerable operation in small-scale heat-transfer systems that satisfactory purity of sodium and sodium-potassium can be obtained by low-temperature filtration of these metals. Oxygen, the principal contaminant, is relatively insoluble at low temperature, and it can be removed from the metals with a fine-mesh filter material. Pore size or mesh in the order of microns is desirable for effective filtration.

Hot sodium and sodium-potassium are good agents for the final cleaning of the system, provided reasonable cleanliness was observed in construction. The metals can be filtered at low temperature after having been circulated in the system at high temperature. Although the effectiveness of this method has its limits, cleanliness during construction is worth the effort.

Gravimetric Investigation into the Oxidation of Copper-Tin Alloys at Various Temperatures

By F. DE CARLI and N. COLLARI. (From *La Metallurgia Italiana*, Vol. 44, No. 1, January 1952, pp. 1-5, 2 illustrations.)

The oxidation rate of a copper-tin alloy at a given temperature depends, among other factors, on the stable phase of the alloy, as shown by investigations with the thermal balance method and photographic recording, developed by the authors[1].

R. F. TYLECOTE[2] recently reviewed existing information on the oxidation of binary and ternary alloys of copper, and his conclusions may be summarized as follows :

(1) The law governing the increase of the oxide layers on copper alloys with noble metals does not differ appreciably from that applying to pure copper; the oxidation rate depends on the copper content of the alloy.

(2) The oxidation of copper alloys with most other metals is generally less than that of pure copper. The increase in oxidation resistance is most pronounced in alloys with aluminium, silicon, beryllium, magnesium, zinc, and tin. In some cases, wide ranges of composition have been studied. The oxidation rate of brass, for instance, is lowest in alloys with 12 to 28 per cent zinc, and the amount of Cu_2O in the oxide layer decreases with increasing zinc content until it disappears completely in brass with 28 to 40 per cent zinc.

(3) (a) The oxidation rate depends on the alloy composition and the rate of diffusion of the atoms or ions in the oxide layer. A protective oxide film forms when the diffusion velocity of one component metal becomes small compared with the other as the oxide film thickens.

(b) Added metals that produce maximum oxidation resistance in an alloy form oxides characterised by minimum values of electrical conductivity.

(c) It is suggested that the formation of a subscale, due to diffusion of oxygen into the alloy and deposition of oxide films on grain boundaries, inhibits the surface oxidation of copper alloys, particularly with aluminium, beryllium, silicon, or magnesium.

Undoubtedly, each of these factors is important, but it is remarkable that the oxidation behaviour has nowhere been related to the nature of the stable phases which an alloy forms within the range of concentrations and temperatures considered. It is known that metallic oxides become more difficult to reduce when present in chemical compounds or solid solutions with other oxides (silicates, aluminates, etc.). Iron oxide, for instance, is more easily reduced when pure than from a mixture of silicate and calcium ferrite, a phenomenon connected with the affinity of the various oxides involved. Similarly, when manganese or magnesium oxides go into solid solution with iron oxide, they appreciably affect the reduction of the iron oxide; whereas the equilibrium concentration of copper oxide in the reduction of pure iron oxide is 64 per cent at 900° C, it rises to 90 per cent when a solid solution of 2FeO.8MnO is reduced. However, the reaction MeO + R = Me + RO is very sensitive to the decrease in free energy occurring when the metallic oxide MeO goes into solid solution with another oxide present. We expect, therefore, that the reaction Me + $\frac{1}{2}O_2$ = MeO will be sensitive to the decrease in free energy when metal Me forms a solid solution or intermetallic compound with another metal. In fact, the oxide MeO is more easily reduced in the presence of a metal Me′ forming a compound or solid solution with Me than when treated alone. Manganese oxide, in the presence of, for instance, iron, has been reduced at temperatures 200 to 300° C lower than has the pure manganese oxide; tin oxide is more easily reduced in the presence of copper. *Thus, when oxides are subject to a decrease in "activity" following the formation of a compound or solid solution, their reduction becomes more difficult. When metals form a compound or solid solution, their combined oxides are more easily reduced, and their oxidation resistance increases.* The following experimental investigations on copper-tin alloys show that the nature of the stable phase of an alloy strongly influences development, composition and behaviour of the oxide layer.

I. *Measurement of oxidation resistance.* The apparatus and test methods have been described in previous sections of this report[1]. Photographic recordings of the gravimetric investigation were taken for seven alloys (Table I) oxidized at temperatures from 500 to 800° C during 3 hours. The test pieces were made from ingots 1 in. in diameter, 3½ in. long, obtained from extremely pure copper and tin molten in a covered graphite crucible inside a Tamman furnace. The molten copper was first de-oxidised with copper containing 0·03 per cent phosphorus and the tin then added. The alloy was homogenized 24 hours at 780° C in a box with dry charcoal, and cooled very slowly in the furnace. A layer of about $\frac{5}{32}$ in. was removed from the circumference of the ingots in order to eliminate any possible traces of surface inhomogeneities. Test results may be summarized as follows :—

500° C. Slight oxidation. After an initial period, during which the first film forms, oxidation increases linearly with time :

$$P = kt + c, \qquad .. \qquad .. \qquad (1)$$

where P = grams of oxygen absorbed per m² of surface area, t = duration of oxidation in minutes (after the

TABLE I.

Alloy No.	Tin weight per cent	Tin atomic per cent	Stable phase at 500° C	600° C	650° C	700° C	800° C
(1)	5·85	3·22	α	α	α	α	α
(2)	11·84	6·74	α	α	α	α	α
(3)	17·47	10·18	$\alpha + \delta$	$\alpha + \beta$	$\alpha + \beta$	$\alpha + \beta$	$\epsilon + \beta$
(4)	23·36	14·08	$\alpha + \delta$	$\alpha + \beta$	$\alpha + \beta$	β	β
(5)	26·60	16·25	$\alpha + \delta$	γ	γ	$\beta + \gamma$	—
(6)	32·70	20·66	δ	γ	γ	—	—
(7)	37·15	24·05	$\delta + \epsilon$	$\zeta + \epsilon$	$\gamma + \epsilon$	—	—

TABLE II.

Alloy No.	1	2	3	4	5	6	7
(500° C):	$P = kt \times c$						
k	0·0125	0·002	0·005	0·0075	0·0014	0·004	0·0009
c	2·41	0·78	1·00	1·31	1·95	0·33	0·20
P	4·72	1·27	1·89	2·71	4·42	1·00	0·49
P_c	4·66	1·14	1·90	2·66	4·48	1·05	0·45
(600° C):	$P^2 = kt$						$P = kt + c$
k	1·91	0·045	0·079	0·44	2·30	0·43	0·01
c	—	—	—	—	—	—	1·30
P	18·19	2·96	3·62	8·65	20·66	8·88	3·17
P_c	18·20	2·84	3·77	8·71	20·40	8·80	3·10
(700° C):	$P^2 = kt$						
k	6·90	2·25	3·52	4·72	13·94	—	—
P	34·41	20·81	25·31	29·00	50·89	—	—
P_c	35·24	20·13	25·10	29·15	50·10	—	—

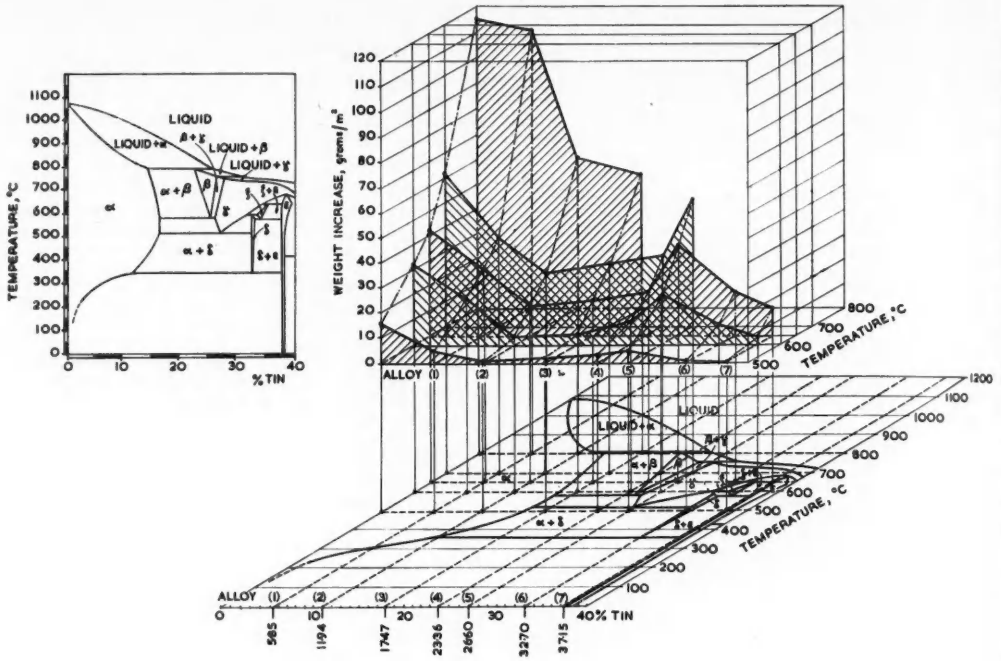

Fig. 1

first 90 minutes), k = oxidation rate in grams per m² per min., c = absorption of oxygen in the initial period of 90 min. Table II gives recorded values of P together with values calculated from eq. (1) for $t = 180$ minutes. Oxidation decreases with increasing tin content, but not regularly. There exists a range of concentrations with minimum values of oxidation. The highest c value (2·41) is obtained for the alloy (1) richest in copper; it falls off appreciably for the next alloys and rises again to 1·95 for alloy (5). Comparison of the various k and c values seems to indicate that the thickness and nature of the initial film must have influenced to some extent the further progress of oxidation.

600° C. Oxidation increases. The curves generally follow a parabolic law (Table II)

$$P^2 = kt \quad .. \quad .. \quad .. \quad (2)$$

Only alloy (7) still obeys the linear law of eq. (1); all the other specimens, after a brief initial period, rapidly increase in weight in the course of a few minutes, after which the oxide layers thicken according to the parabolic law. The trend noticed at 500° C is even more pronounced: susceptibility to oxidation is markedly lower for alloys (2), (3), (4), (6), (7) than for alloys (1), (5) and pure copper; the P value of alloy (5) even exceeds that of alloy (1).

650° C. Alloys (1) to (6) follow the parabolic law, alloy (7) follows eq. (1) with the constants $k = 0{\cdot}057$, $c = 0{\cdot}12$. The rise in oxidation resistance of the intermediate alloys is again confirmed.

700° C. Measurements had to be limited to alloys (1) to (5). Oxidation is still parabolic (Table II). The relative decrease in oxidation of alloys (2), (3), (4) is less marked, but the increased oxidation of alloy (5), as compared with (1), is even more pronounced. The greater mobility of metallic ions at higher temperatures may partly account for, but cannot entirely explain, these changes. Evidently, certain factors characterising the behaviour of each alloy and changing with the condition of its stable phase at the test temperature affect the properties of the oxide layer and enable it to resist thermal stresses. The observed phenomena may tentatively be explained by reference to the appreciable variations in the free energy of formation of the binary phases.

II. *Appearance and composition of the oxide layer.* On removal from the furnace, specimens of alloy (1) oxidized at 500 to 700° C were covered with a uniform black scale which detached itself spontaneously during cooling. The surface of the scale in contact with the metal had a white appearance, whereas scale formed at 800° C was dark throughout. Alloys (2) to (5) oxidized at 500 and 600° C had very thin oxide layers which adhered down to room temperature. At 500° C a bright bluish-black surface was sometimes obtained. At 700° C the scale was easily detachable and black throughout after cooling. The scale of alloys (6) and (7) had the same appearance as that of alloys (2) to (5), but was less easily detachable. Wherever possible, an analysis of the copper and tin content of the scale was made (Table III). The conclusions are:

TABLE III. COMPOSITION OF OXIDE LAYER.

Alloy	500° C	600° C	650° C	700° C	800° C
(1) Cu	75·58	83·24	—	82·68	80·64
Sn	8·89	3·30	—	3·35	4·94
(2) Cu	—	—	—	60·11	68·87
Sn	—	—	—	23·79	17·17
(3) Cu	—	—	—	41·20	—
Sn	—	—	—	38·56	—
(4) Cu	—	38·46	—	39·08	33·02
Sn	—	37·86	—	35·64	40·58
(5) Cu	—	14·79	—	20·08	33·02
Sn	—	63·25	—	59·52	40·58
(6) Cu	—	10·87	14·95	—	—
Sn	—	70·21	62·81	—	—

(1) The Cu-Sn ratio in the scale does not vary proportionally with that of the alloy.

(2) The progressive decrease in oxidation of the various α-alloys coincides with a constant Cu-Sn ratio in the oxide layer. This ratio, nearly 2 : 1 in alloys (3) and (4), might indicate a film of $Cu_2O{\cdot}SnO_2$.

(3) The scale of alloy (5) has a Cu-Sn ratio very similar to that of alloys (6), (7). The great difference in oxidation resistance should therefore be related to the difference in behaviour of the alloy phases forming the scale rather than to the nature of the scale itself.

(4) Oxidation varies discontinuously with increasing tin content. Only within certain limits of concentration is the oxide layer really protective. Alloy (5) with 26·6 per cent Sn interrupts the falling trend in oxidation of alloys (1), (2), (3), (4) and (7); it oxidises more readily than alloy (1) with 5·85 per cent Sn. The nature of the oxide layer thus may play a role with alloys (2), (3) and (4), but cannot be regarded as a decisive factor for alloys (6) and (7).

III. *Relation between oxidation and composition of alloy.* In Fig. 1, the weight of oxygen adsorbed at various temperatures by the various alloys is plotted above a base plane representing the copper-tin equilibrium diagram. The discontinuous variations of oxidation can be clearly seen :—

(1) Oxidation definitely decreases from the high value for pure copper through the stable region of the α-phase to its saturation limit.

(2) Alloys (3) and (4), situated in the stable β-region, show that the β-phase, though more resistant than pure copper, oxidizes more easily than α.

(3) The γ-phase is easily oxidized and causes the

(*Concluded on page* 193)

RUSSIA

Vibration Pick-up with Large Frequency Range

By Y. I. YORISH. (From *Elektrichestvo*, No. 9, 1951, pp. 54-57, 11 illustrations.)

A seismic vibration pick-up is described, in which a permanent magnet is suspended as a seismic mass on bimetallic leaf springs with a helical spring support for gravity. Measurements of frequency and amplitude characteristics and temperature sensitivity are given.

THE mechanical properties of a vibration pick-up depend on the suspension system of the seismic mass. The most important types of suspension are: (a) the vibrating mass, moving along linear guides; (b) the vibrating mass being guided by a system of leaf springs. The second method requires greater bulk, but practically eliminates friction and therefore yields a much lower threshold of sensitivity.

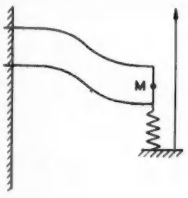

Fig. 1 (above). **Suspension of seismic mass on two leaf springs, with helical spring support.**

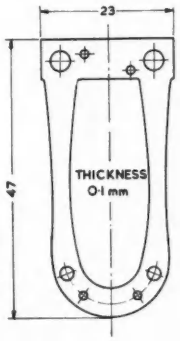

Fig. 3 (right). **Detail of leaf spring.**

This article describes a design based on a suspension system shown diagrammatically in Fig. 1. A spiral spring is added to the leaf spring system. The spiral spring has a low stiffness but is strong enough to carry the weight of the seismic mass. The leaf spring system maintains the axis of the mass parallel to itself, though a small bodily displacement takes place.

In practice, the upper limit of the frequency band is determined by the higher resonant frequencies of the springs. The design described here has no disturbing resonance frequencies within the pertinent frequency range. This is achieved in part by making use of the internal damping of the spring material.

Normally, metals suitable for springs, such as spring steel, phosphor bronze and beryllium copper, have a low coefficient of internal damping. Metals with considerable damping properties, such as soft copper, lead, tin and others, are not suitable as spring materials. In the pick-up described here, a bimetallic spring is used, combining the properties of spring metal and damping metal. A tin-coated steel spring has been found satisfactory to damp out the resonance peaks within the frequency range of the instrument.

Fig. 2 shows a section of the pick-up. The permanent magnet (1) made of " magnico " alloy together with its fittings constitutes the seismic mass of the pick-up and is suspended on two leaf springs (2) shown in detail in Fig. 3. The natural frequency of the system is 7 to 8 cps. The magnetic flux traversing the air gap is closed through the cylindrical body (3). In this body, a

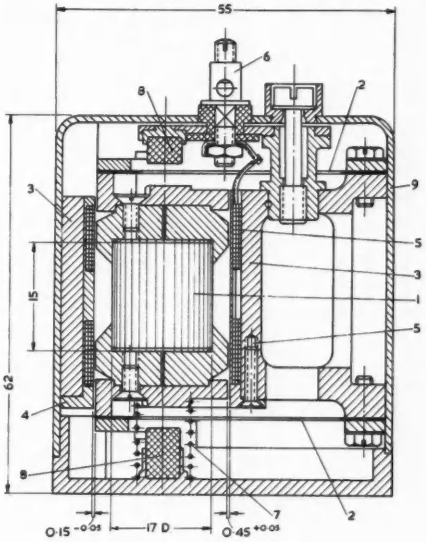

Fig. 2. **Sectional view of pick-up.** Dimensions in millimetres.

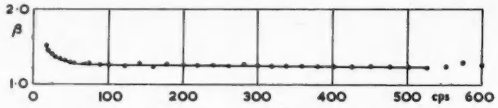

Fig. 4. **Frequency characteristics of pick-up.**

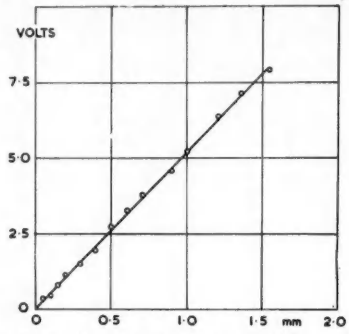

Fig. 5. **Amplitude characteristics of pick-up at 50 cps.**

brass spool (4), carries two windings (5) connected in series. One end of the windings is led to the contact screw (6) and the other is electrically connected to the body of the pick-up, which is mounted on the component to be investigated. The movement of the windings, together with the body, relative to the seismic mass induces a voltage in the windings, the magnitude of which is proportional to the velocity of the relative movement, provided the magnetic flux is constant.

When the pick-up is used in a vertical position, the weight of the seismic mass is compensated by the soft coil spring (7). Bumpers (8) preserve the vibrating system from excessive movement and the whole pick-up is enclosed under cover (9).

Fig. 4 shows typical frequency characteristics, in which the sensitivity β is plotted over the frequency. This sensitivity is defined as the ratio of the output voltage of the pick-up to the output voltage of the transmitter attached to a calibrating cable. The amplitude graph is shown in Fig. 5. The output voltage of the pick-up is plotted against the vibration amplitude and there is no deviation from the linear relation either at small vibration amplitudes of the order of 1μ or at large amplitudes of the order of 1·5 mm. The threshold of sensitivity, whether in the working frequency range or at the lowest frequencies of 3 to 5 cps lies below 1μ.

The sensitivity of the pick-up depends on the number of turns of the winding, other things being equal. A winding of 0·04 mm wire having 4000 turns gives a sensitivity of about 150 mV/mm cps.

This pick-up is intended for the measurement of steady periodic motion, and hence no additional damping is introduced to damp effectively the lowest natural frequency of the system. The specific damping is 3 per cent of critical and, hence, even at 10 cps, the phase lag does not exceed 6 degrees and at 50 cps falls below 30 minutes. This pick-up is practically free from interference by components of vibratory motion at right-angles to the axis of the instrument. Precise measurements of the degree of interference were not possible because no vibrating tables exist which produce purely linear vibrations. It is known, however, that the degree of interference is considerably below 5 per cent. The sensitivity of the pick-up to an inclination of its axis against the direction of vibration obeys the cosine law at least as far as 20 deg. of inclination. Thus, the error at 20 deg. does not exceed 6 per cent. The dependence of the amplitude characteristics of the pick-up on the ambient temperature is shown in Fig. 6.

The weight of the pick-up is 350 grams and its

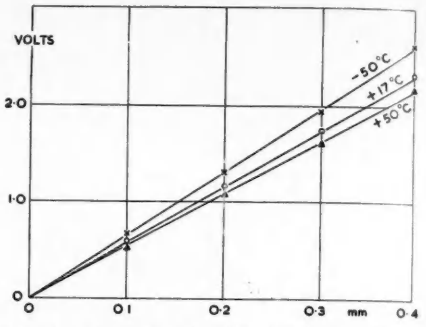

Fig. 6. **Amplitude characteristics of pick-up at 50 cps and different ambient temperatures.**

dimensions 38 × 55 × 62 mm. The lowest natural frequency determines the weight and bulk of the pick-up Thus, a 9-cps design weighs 175 grams, and a 5-cps design weighs 1 kg.

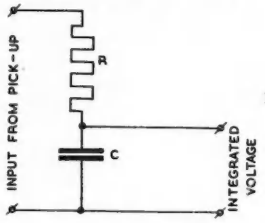

Fig. 7. **Integrating circuit.**

It is usual to convert the velocity signal of the pick-up into a displacement signal by means of an integrating circuit as shown in Fig. 7. It has been shown that the perfection of integration depends on the product RC, but this property can be used for the correction of undesirable frequency characteristics. In

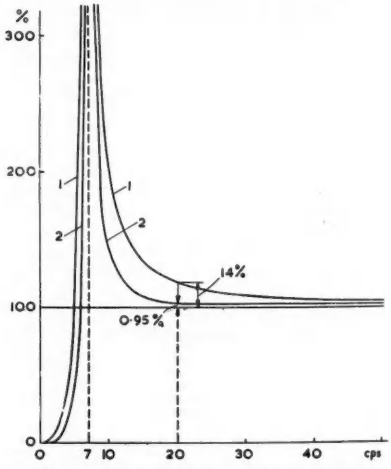

Fig. 8. **Frequency characteristics of pick-up.**
Curves (1): Large RC in integrating circuit.
Curves (2): R = 4000 ohms. C = 3 μF.

Fig. 8 the ratio of measured and actual amplitudes is plotted over the frequency. Curves (1) illustrate perfect integration. Curves (2) illustrate the deliberate suppression of amplitudes at low frequencies by means of a small value of RC.

The Calculation of Thick-Walled Cylindrical Shells of Carbon Steel subject to Internal Pressure

By W. P. KERKHOF. (From *De Ingenieur*, Vol. 64, No. 18, May 2, 1952, pp. W 21-W 24.)

ALL pressure vessels or boilers must be designed to avoid permanent deformations and rupture due to yielding or creep. Many of the existing codes for pressure vessels are based on the theory of maximum stress, which is used as a criterion for determining permanent deformation and rupture. This leads to simple formulae which are easily applied.

However, it is a fact that maximum stress is not the value which determines behaviour in regard to rupture or deformation, and that the other principal stresses and shear stresses have a considerable effect. Furthermore, it is necessary to take account of plasticity for deformations exceeding the elastic limit, and to consider the effect of creep at high temperatures on stress distribution.

Assuming that a theory of deformation and rupture is known, it will in this case lead to very complicated expressions. It will therefore be preferable to retain the simple formulae for maximum stress and to multiply these by a factor which takes account of the influence of the state of stress on rupture or deformation.

The calculated stress obtained in this manner will not be the actual stress but a value of permissible stress based on a uni-axial tensile or creep test which corresponds to the same permanent deformation or the same safety factor against rupture as the true stresses occurring in the shell. This method which results in simple formulae used with tabulated values for allowable stress will now be described.

BASIC FORMULAE

Cylindrical shells with a wall thickness $2t$ not greater than 10 per cent of the inside diameter D_i are usually calculated by means of either one of the two following equivalent formulae:—

$$t = pD_m/2s \quad \text{or} \quad t = pD_i/(2s - p) \quad .. \quad (1)$$

where p = internal pressure, D_m = mean diameter, and s = permissible stress, allowing for weld efficiency in the case of welded vessels.

When the thickness $2t$ is greater than $D_i/10$, Lamé's formula is used:—

$$t = (D_i/2)\,[\sqrt{(s + p)/(s - p)} - 1] \quad .. \quad (2)$$

In both formulae, s is the maximum stress occurring in the shell, assuming that the cylinder is perfectly circular. The possibility of utilising these equations as criteria for permanent deformation will now be investigated.

YIELDING AT THE INNER SURFACE OF THE CYLINDER

In the elastic state, the stresses have maximum values at the inner surface and yielding begins, therefore, on this surface. The formulae of Lamé for the elastic stresses s_c, s_r and s_a of the inner surface, in the circumferential, radial and axial directions, respectively, are

$$s_c = p\,(k + 1)/(k - 1), \quad .. \quad .. \quad .. \quad (3)$$

$$s_r = -p, \text{ and } s_a = p/(k - 1) \quad .. \quad (3'), (3'')$$

where $k = (D_o/D_i)^2$, D_o being the outer diameter.

The investigations of thick-walled cylinders carried out by Lode and by Taylor and Quinney showed that the yielding is determined by the shear stress in the octahedral plane. According to the formula usually known as the von Mises-Hencky-Huber equation, but already indicated by Maxwell nearly 100 years ago, yielding at the inner surface occurs when

$$(s_c - s_r)^2 + (s_a - s_c)^2 + (s_r - s_a)^2 = 2s_y^2 \quad .. \quad (4)$$

where s_y = yield stress of the material in simple tension.

For a thick-walled cylinder, by using eqs. (3), (3′) and (3″), eq. (4) can be reduced to

$$\sqrt{3}\,k\,p/(k - 1) = s_y \quad .. \quad .. \quad (5)$$

so that, for given values of s_t, D_i and p,

$$t = (D_i/2)\,[\sqrt{s_y/(s_y - \sqrt{3}\,p)} - 1] \quad .. \quad (6)$$

Equations (5) and (6) are frequently used with a factor of safety against yielding for determining the wall thickness.

Table I shows the values of p/s obtained using eq. (2) compared with values from eqs. (5) and (6) with a safety factor against yielding. For a given value of allowable stress s, the latter equations give lower p/s ratios. It is thus usual to allow a low safety factor when using the Maxwell-Lamé equations (5) and (6).

TABLE I

t/D_i =	0·1	0·2	0·3	0·4
p/s =	0·181	0·323	0·439	0·529 (eq. (2))
p/s =	0·176	0·282	0·351	0·397 (eqs. (5) & (6))

If, instead of the shear stress in the octahedral plane, the maximum shear stress is taken, according to Guest, as a criterion for yielding, the p/s values are slightly lower than those based on eqs. (5) and (6). As the differences are not great, Guest's formulae can also be used, and these are somewhat simpler.

DEFORMATION AND RUPTURE AT TEMPERATURES BELOW 650° F

The deformation of the inner surface obtained with eqs. (5) and (6) cannot be regarded as excessive. The yielding is considered excessive when it occurs over the entire wall thickness. The following treatment is based on Guest's criterion of maximum shear stress, which is considered to be more in accordance with the real behaviour of the material when excessive yielding occurs.

The formula for yielding over the whole wall thickness was developed by van Iterson in 1912, but it is of interest to consider its derivation. According to Guest, in a uni-axial state of stress, the maximum shear stress q remains constant and is equal to the yield shear stress. Since in the cylinder the radial stress s_r is compressive, the value of q is always given by

$$q = (s_c - s_r)/2 \quad .. \quad .. \quad (7)$$

For a uni-axial tension test, the maximum shear stress is $q = s/2$, s being the tensile stress. Therefore this gives

$$s = s_c - s_r \quad .. \quad .. \quad (8)$$

When the yield point is reached, the tensile stress s in a test rod is equal to the yield stress s_y. Therefore, during the yielding of the cylinder, the above equation is equivalent to

$$s_y = s_c - s_r \quad .. \quad .. \quad (9)$$

In this expression, the stiffening effect due to yielding is neglected, and this again gives values on the safe side. From symmetry considerations, it follows that s_c and s_r must be principal stresses. This means that no shear stress acts on the planes of s_c or s_r.

The equation for equilibrium in the radial direction is

$$p\,r_1\,d\varphi - s_r\,r\,d\varphi + d\varphi \int_{r_i}^{r} s_c\,dr = 0$$

Eliminating $d\varphi$ and differentiating, we obtain

$$-s_r\,dr - r\,ds_r + s_c\,dr = 0$$

and in conjunction with eq. (9) this gives

$$s_y\,(dr/r) = ds_r$$

or

$$s_r = s_y \log_e r + C$$

The integration constant is determined from the condition that the radial stress s_r is zero on the outer surface, so that

$$C = -s_y \log_e r_o$$

Thus

$$s_r = s_y \log_e (r/r_o) \quad .. \quad .. \quad (10)$$

At the inner surface, $s_r = -p$. Therefore, the cylinder yields over the entire wall thickness when

$$p = s_y \log_e (r_o/r_i) \quad .. \quad .. \quad (11)$$

When, in order to obtain a factor of safety against yielding, a lower stress value is used in the place of s_y, excessive deformation is avoided, but the stress indicated by the above formula no longer represents the actual stress occurring in the cylinder.

Values calculated by means of eq. (11) are given in Table II. Compared with the values of Table I, they show that eq. (11) gives a smaller wall thickness than eqs. (2), (5) and (6).

TABLE II

t/D_i =	0·1	0·2	0·3	0·4
p/s =	0·182	0·337	0·470	0·588

Furthermore, eq. (11) may be rewritten as

$$e^{(p/s)} = r_o/r_i = D_o/D_i$$

and since $D_o/D_i = 1 + (2t/D_i)$, the series expansion of $e^{(p/s)}$ gives

$$\frac{2t}{D_i} = \frac{p}{s} + \frac{1}{2!}\left(\frac{p}{s}\right)^2 + \frac{1}{3!}\left(\frac{p}{s}\right)^3 + \frac{1}{4!}\left(\frac{p}{s}\right)^4 + \ldots \quad (13)$$

For very thin-walled vessels, the first term of the expansion is sufficient. Therefore

$$t = pD_i/2s \quad .. \quad .. \quad (14)$$

which is the same equation as eq. (1) if D_i is replaced by D_m, which is justifiable for very small values of t.

As equation (14) is used in conjunction with the usual values for permissible stresses, and is, furthermore, only a special case of the general formulae (12) or (13), it is possible to use in these equations the same values for permissible stresses as previously. The factor of safety against extensive deformation is then the same for thin-walled and for thick-walled vessels.

Equation (12) is valid up to the point of rupture. In this case, the value s_y (representing the yield stress) should be replaced by the value s_{UTS} of the tensile test rod.

According to Roš, static rupture is caused by the maximum shear stress, so that Guest's theory is valid. This theory was used to obtain eq. (12). It is also advocated by van Iterson when excessive yielding occurs. In order to test the validity of eq. (12) and Guest's theory, values of p/s_{UTS} were calculated by means of this equation and are compared in Table III with the results of tests made by Cook and Robertson on thick-walled cylinders.

It is thus evident that eq. (12) gives good results not only as regards excessive deformation but also in regard to rupture. Equation (12) should, therefore, be used for thin-walled as well as for thick-walled vessels, at temperatures below 650° F (350° C).

NUMERICAL EXAMPLE

We shall assume that it is required to calculate the internal pressure of a cylinder for which $D_i = 40$ in., $D_o = 64$ in., and $t = 12$ in. Material: carbon steel, with a U.T.S. of 28 tsi and a minimum yield point estimated at 31,500 psi. The cylinder will be assumed to be forged, so that no weld efficiency has to be taken into account.

TABLE III

D_o/D_i	p/s_{UTS}	p/s_{UTS}	U.T.S. calc. value / U.T.S. test value
1·35	0·302	0·312	1·030
1·58	0·457	0·457	1·000
1·67	0·512	0·465	0·911
1·77	0·572	0·569	0·991
1·79	0·581	0·597	1·023

Mean value = 0·975

According to the existing codes, a safety factor of 3 relative to the U.T.S., or 1·5 to the yield point, should be used. The allowable stress is therefore 20,900 psi. According to eq. (12) or Table II, for $D_o/D_i = 1{\cdot}6$ the allowable pressure is 9800 psi. The circumferential stress at the inner surface, determined by means of eq. (2) or Table I, is 22,200 psi, which is higher than the allowable stress of 20,900 psi for simple tension. For the outer surface, the circumferential stress is obtained from Lamé's formula

$$s_{c(r_o)} = 2p/(k-1) \quad .. \quad .. \quad (15)$$

where $k = (D_o/D_i)^2$, and is equal to 12,600 psi, which is much lower than the allowable stress for simple tension. Using eq. (5), the lowest value of the yield point at the inner surface is found to be 28,000 psi, the true value of s_y being 31,500 psi. Therefore, at the inner surface, the safety factor relative to the yield point is 31,500/28,000 = 1·12. This is a very low value, but it should be noted that 1·5 is a safety factor for thin shells, and it can be reduced in cases where the stresses are local, as in this example. For instance, for domed ends, a safety factor of 1·1 relative to the yield point is frequently permitted. The figure obtained above coincides with this value and the recommended formula gives, therefore, values in agreement with good normal practice. When the cylinder is calculated with the usual formula (eq. (2)), the wall thickness should be $13\frac{13}{32}$ in. (340 mm).

DEFORMATION AND RUPTURE AT TEMPERATURES ABOVE 650° F (350° C)

At these temperatures, the effects of creep must be taken into account. For carbon steel pipes having a high ductility under creep conditions, the following formula has been recommended by Bailey:

$$s = p \times (0{\cdot}5)^q \times 3^{(1+q)/2} \times q/[k^q - 1] \quad .. \quad (16)$$

where $k = (D_o/D_i)^2$, and s represents the uni-axial stress in a creep test bar causing the same creep strain as that occurring at the outside of the cylinder. The factor q is a constant, dependent on the material and the state of creep. According to Bailey, $q = 0{\cdot}5$ is a safe mean value, but q may decrease to 0·125 in some cases, in the tertiary state of creep.

TABLE IV

t/D_i =	0·1	0·2	0·3	0·4
p/s =	0·249	0·498	0·747	0·996 (for q = 0·5)
p/s =	0·221	0·414	0·588	0·742 (for q = 0·125)

The actual stresses in the cylinder are much higher than those given by eq. (16), and are similar to the s-values obtained with eq. (12) at lower temperatures. Values of p/s determined by means of eq. (16) are shown in Table IV. The permissible internal pressure is much higher than previously.

(*Concluded on page* 196)

The Effect of Diamond Wheel Grinding on the Surface Finish of Sintered Carbides

By E. DINGLINGER. (From *Werkstattstechnik und Maschinenbau*, Vol. 42, No. 2, February, 1952, pp. 50-56, 13 illustrations.)

In order to reach sound conclusions from metal cutting research, many variables including tool angles, cutting speeds and feeds, cooling and heating must be taken into account. An additional variable which, if not controlled, can completely vitiate research results, is the keenness and surface finish of the cutting tool. This was first established in machining tests on wood, plastics and other similar materials; it was also found that the optimum finish was not necessarily the finest. It appears that various materials require varying grades of tool finish for most satisfactory machining.

METAL machining investigations in England, Germany and the U.S.A. have established definite differences in cutting tool life between finish ground tools and tools which were only rough machine ground and finished by hand. Quantitative values of the surface finish of the tools used in this work are unfortunately not available. It would be of little practical value merely to establish and specify optimum values of tool finish for further metal cutting research. It is essential that the method of obtaining these finishes should also be established and clearly specified.

The present trend towards higher cutting speeds brings into prominence sintered carbide cutting tools. Although some data on the finish of carbide tools are already available, no systematic investigations have so far been carried out on the effect of the various grades of surface finish on the cutting quality of carbide tools. The present work is not concerned with rough and semi-finish grinding, but only with the final stage, i.e., finish grinding.

Finish grinding involves the use of diamond wheels, and the first step, therefore, is the determination of the effect of diamond particle size and various wheel bonds. As shown below, the various bonds such as synthetic resin, bronze or steel affect the finish of the ground tools to a considerable extent. Conversely, identical wheels used in an identical manner on a number of different carbide grades also result in varying finishes. Results which are applicable in practice can therefore only be obtained by using a number of different carbides in conjuction with a series of diamond wheels having various particle sizes and bonds. A very large number of tests was thus required, when the variables were established as seven grades of carbides, seven diamond particle sizes and three types of bond. Many of the tests had also to be repeated twice or three times. The aim of this research, which was carried out at the Institute for Machine Tools at the Hanover Technical High School in close co-operation with A. Heiss, was to establish practical data, so that specified finishes of carbide tools could be obtained without prior trial and error. The most commonly used grades of carbides were selected. These are: Tungsten carbides H 1, G 1 and G 2, and tungsten titanium carbides F 1, S 1 and S 2 (see Table I). All tool grinding was carried out in a standardized manner, identical with that used in practice, to obtain data directly applicable in the workshop. The diamond wheels had a diameter of 6 in., a thickness of $\frac{1}{8}$ in. and a diamond concentration of 15 carats with a layer thickness of 0·040 in. Water cooling was used throughout. The tools were wholly made of carbide, and brazed tips were not used. The cutting edge was

TABLE I. APPLICATIONS OF THE VARIOUS GRADES OF CARBIDE TOOLS

F 1	Suitable for finish machining of steel, small chip cross-sections.
S 1	Suitable for high-speed machining of steel; feeds up to 1 mm/rev.
S 2	Suitable for machining of steel; speeds 0·7 of S 1 feeds up to 2 mm/rev.
S 3	Suitable for machining of steel; speeds 0·5 of S 1; feeds up to 3 mm/rev.
G 1	Suitable for machining of cast iron, copper, brass, light alloys.
G 2	Suitable for machining of plastics, wood.
H 1	Suitable for machining of chilled cast iron, cast steel, glass, ceramics.

30μ DIAMOND PARTICLES IN SYNTHETIC RESIN BOND

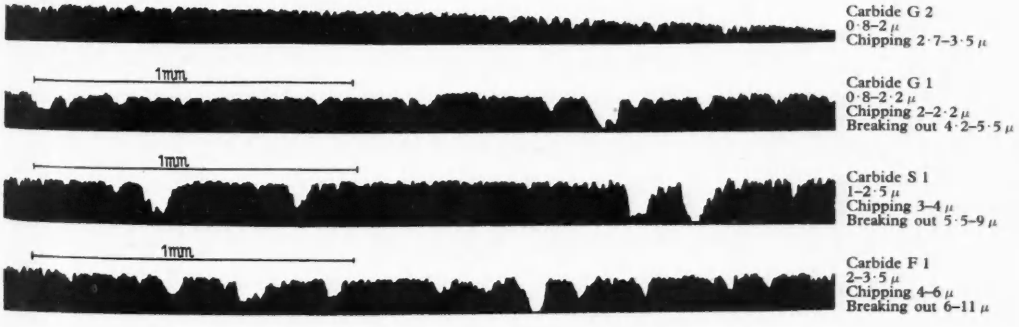

Fig. 1. Surface finish of sintered carbide cutting edges.

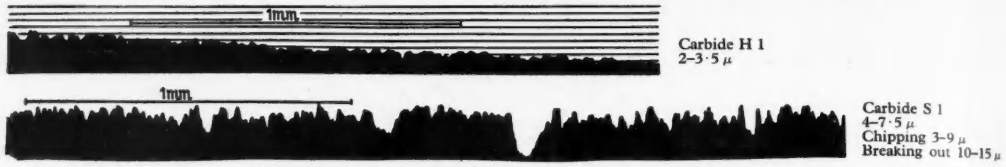

Fig. 3. **Surface roughness records.**

0·640 in. long with a relief angle of 8 deg. and 0 deg. rake. The latter was chosen so that the finish for positive as well as negative rakes could be determined relatively easily. A Leitz surface finish tester was used for determining the surface finish values.

I. GRINDING OF CARBIDE TOOLS WITH SYNTHETIC RESIN-BONDED DIAMOND WHEELS.

The various grades of carbides were firstly ground with synthetic resin bonded diamond wheels with particle sizes from 150μ to 7μ*, and the appropriate rough and semi-finish grinding procedure was followed in every case. It was found that a given wheel resulted in various finishes when used on different carbide grades. The effect on carbide grades H 1, G 1, G 2, S 1 and F 1 is illustrated in Fig. 1. The vertical magnification is × 300 and the horizontal magnification is × 50, all the tools being ground with the same resin-bonded wheel containing 30 μ diamond particles. It

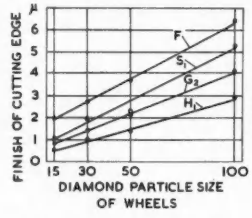

Fig. 4. **Differences in surface finish values of various carbide grades, ground with the same wheels (synthetic resin-bonded diamond wheels).**

will be noticed that, in addition to variations in the average surface finish, a variation in the depth of chipping is also evident; this ranges from 2·2 μ on the H 1 carbide to 6-11 μ on the F 1 grade. Fig. 2 summarises the average surface finish values, which include chipping, of the seven carbide grades. It can be seen that the best finish (1 μ) is obtained on grade H 1, whereas grade F 1 appears to be the most vulnerable, with a finish of 2·8 μ. Table II presents all the values for the various grades, and it is evident that the differences between G 1 and G 2, and S 2 and S 3 are not significant. The change from a fine grit wheel of 15 μ to a coarser wheel of 100 μ particle size results in the following changes in average surface finish:

Grade H 1 from approx. 0·5 μ to approx. 2·75 μ.
Grade S 1 from approx. 1·2 μ to approx. 5·75 μ.

Fig. 3, however, illustrates yet another difference. H 1 shows almost no chipping, whereas grade S 1 shows chipping of 10-15 μ and "breaking-out" of 9 μ. The surface finish values of the various carbide grades ground with resin-bonded wheels with particle sizes ranging from 15 μ to 100 μ are plotted in Fig. 4, the total finish range being 0·5 μ to 6 μ. The varying effect of grinding with identical diamond wheels on various carbide grades is clearly indicated.

TABLE II. CUTTING EDGE FINISH OF VARIOUS CARBIDE GRADES AFTER GRINDING WITH A RESIN-BONDED 30μ DIAMOND WHEEL.

Carbide grade	Surface finish μ	Chipping μ	Breaking out μ	Remarks (No. of "breakings-out")
F 1	2·5–3·5	4–6	6–8–11	10 in 5 mm length of cutting edge
S 1	1·3–2·7	3–3·5	5·5–12·5	5 in 2·5 mm length of cutting edge
S 2	1·0–2·5	3–4–5·5	5·5–9–15	4 in 4 mm length of cutting edge
S 3	1·0–2·2	2·5–3·5	7	1 in 5 mm length of cutting edge
G 1	0·8–2·2	2·5–3·5	4·2–6–10	8 in 2·5 mm length of cutting edge
G 2	0·8–2·0	2·7–3·5	——	None. 1 groove of 5·5 μ
H 1	0·3-0·8-1·8	2·0–2·2	3·2	None. 1 groove of 3·2 μ

II. GRINDING OF CARBIDE TOOLS WITH BRONZE-BONDED WHEELS.

In general, the finishes obtained were inferior to those obtained with resin-bonded wheels, and the same differences between various carbide grades as previously found were present. Fig. 5 shows three cutting edge profiles. These belong to grades H 1, S 2 and F 1, which were ground with a bronze-bonded wheel having a 100 μ particle size. As shown, the surface finish values are: H 1 : 4-7·5 μ, S 2 : 6-9 μ and F 1 : 6-11 μ.

*1μ = 0·001 mm = 0·00004 in.

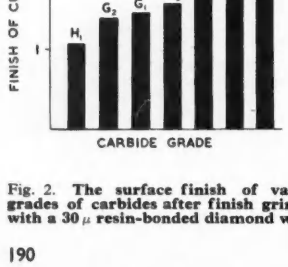

Fig. 2. **The surface finish of various grades of carbides after finish grinding with a 30 μ resin-bonded diamond wheel.**

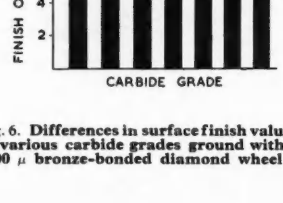

Fig. 6. **Differences in surface finish values of various carbide grades ground with a 100 μ bronze-bonded diamond wheel.**

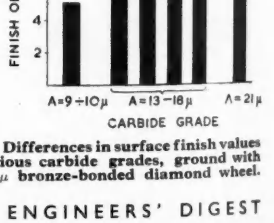

Fig. 7. **Differences in surface finish values of various carbide grades, ground with a 150 μ bronze-bonded diamond wheel.**

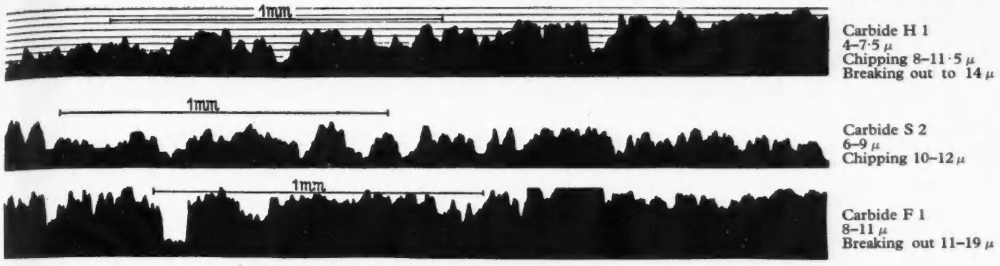

Fig. 5. **Carbide tool cutting edge profiles.**

CARBIDE GRADE S 1, GROUND WITH 50μ DIAMONDS IN:

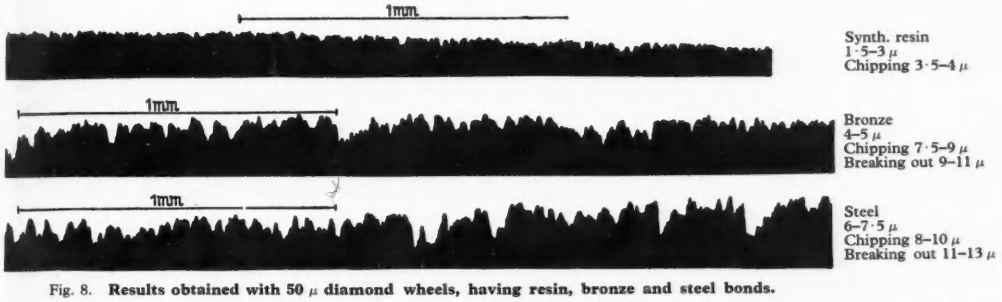

Fig. 8. **Results obtained with 50 μ diamond wheels, having resin, bronze and steel bonds.**

CARBIDE GRADE S 1, GROUND WITH 100μ DIAMONDS IN:

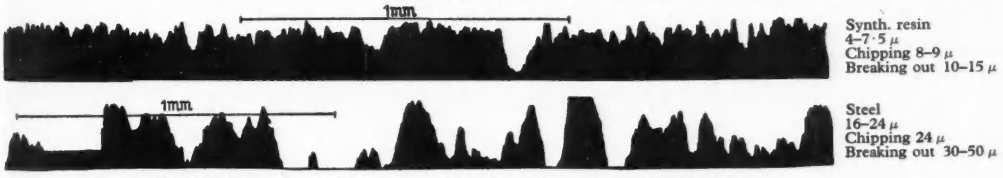

Fig. 9. **Results obtained with 100 μ diamond wheels having resin and steel bonds.**

The finishes of the other grades lie within the above values, and all the average values for a 100 μ diamond wheel are summarized in Fig. 6. When comparing Fig. 2 with Fig. 6 it becomes clear that the average values with the bronze bond are higher than those obtained with the resin bond, but the variation between H 1 and F 1 is smaller with the bronze bond. This variation between the various carbide grades is amaller still when using a bronze-bonded diamond wheel with 150 μ diamond particles as shown in Fig. 7. Clearly, the average finish of the G and S groups is similar, whereas that of H 1 is almost 50 per cent lower and that of F 1 is 25 per cent higher. Similarly, the chipping of the G and S groups is of the same magnitude and has a depth of some 13-18 μ; with grade H 1 the depth is 9-10 μ and grade F 1 has a depth of about 20 μ. A comparison of the values in Figs. 6 and 7 shows that the effect of coarser particles is almost negligible with grade H 1, i.e., considerably less than with the other grades. The effect is most marked with grade F 1, and it is clearly shown that grade H 1 can be given the best finish with existing diamond wheels.

Further tests were carried out with a 250 μ particle bronze-bonded wheel, and the surface finish values were generally more than 20 μ. The variations between various carbide grades become gradually less significant with increasing particle size. The adhesion of the carbide grains in the bond was severely tried by the heavy blows of the large diamond particles and the resulting effect was similar for all the grades. This work with coarse diamond wheels was therefore not pur ued further, as it overlaps the sphere of silicon carbide wheels. According to Dawihl, the finish of a carbide tool ground with a silicon carbide wheel was between 8 and 15 μ, and some measurements by Heiss give the surface finish value of an S 1 carbide tool ground with a silicon carbide wheel type 120 J as 6 to 12 μ.

The most important finding is the determination of the particle size value, after which the various carbide grades show varying finishes.

III. Grinding of Carbide Tools with Steel-bonded Diamond Wheels.

In comparison to resin and bronze bonds, the steel-bonded wheels, for a given particle size, produced rougher cutting edges. This is exemplified in Figs. 8 and 9. The former shows the results of grinding an S 1 grade carbide tool with 50 μ diamond wheels having resin, bronze and steel bonds. Fig. 9 illustrates the comparison between a resin and steel bond for a 100 μ particle size. In both cases the finish produced with the steel-bonded wheel is inferior. Steel-bonded wheels, however, do have many applications due to their rapid grinding and their suitability for semi-finishing operations. The bronze-bonded wheels are also suitable for this purpose and produce a finer surface finish, but they wear more rapidly than the steel-bonded wheels.

IV. Comparison of the Three Bonds with Varying Diamond Particle Sizes.

The surface finish values achieved when grinding with wheels having resin, bronze and steel bonds are

plotted against diamond particle size (15 μ to 250 μ) in Fig. 10. This example refers to carbide grade S 1, but similar diagrams were prepared for all the seven grades. The relationships for the other grades are similar to that illustrated, the only difference being the actual surface finish values. The lowest surface finish values were achieved with the resin-bonded wheels. These were followed by values obtained with bronze-bonded wheels and the steel-bonded wheels gave the roughest finish. Values for diamond particle sizes greater than 150 μ are not included because, as mentioned above, these would overlap results obtained with silicon carbide wheels.

The differences in surface finish obtained with the various bonds could be ascribed to the varying elasticities of the bonds. The elasticity ratio of synthetic resin to that of steel is about 20 to 1. The synthetic resin bond is thus 20 times as elastic as the steel bond, the bronze bond having an intermediate value. Another possible influence is the self-sharpening effect of the diamond particles, i.e., a very strong bond, retaining the diamonds too long, may influence the resulting finish.

V. Lapping of Carbides on a Cast Iron Plate with Loose Diamond Particles.

The use of loose particles for lapping is generally assumed to give very fine finishes. During the present investigation, however, it was found that the grinding of a carbide tool grade S 1 with a resin-bonded wheel of 15 μ particle size resulted in a finish of 1·2 μ (chipping 2-3 μ), whereas the same tool lapped with loose 3 μ diamond particles showed a finish of 1·75 μ (chipping 3-4·5 μ). This average finish corresponds to one obtained with a resin-bonded wheel with 30 μ diamonds, and the chipping is similar to that resulting from grinding with a 50 μ diamond wheel. This great difference can be attributed to the fact that when the diamond particles are embedded, only a small part of them is actually used and at a certain stage of wear they break out from the bond. When lapping, however, the whole particle is continuously in use.

VI. Data Tables for Practical Application.

In order to make the results of these investigations readily applicable in practice, the author has prepared a number of tables. These permit a rapid selection of the correct diamond grinding wheel bond and particle size to impart the required surface finish to any particular carbide grade. Table III is laid out for rapid and simple use, and some slight approximations of the test results had to be made to achieve this object.

VII. The Effect of Tool Angles on the Roughness of the Cutting Edge, with Constant Finish of the Rake and Clearance Faces.

The theoretical relationship between the finish of the cutting edge and its two adjacent surfaces was calculated by Heiss. He demonstrated the increase in roughness with a decreasing wedge angle, and this relationship is shown graphically in Fig. 11. As mentioned above, the wedge angle of the tools used in the present investigation was 82 deg. The value given by the curve in Fig. 11 is 1 at 180 deg., and at 82 deg. it is 1·5. If, for example, the equivalent values to those shown in Table III were required for a tool having a wedge angle of 60 deg., a conversion ratio of 2 : 1·5 would have to be used. For a 28 deg. wedge angle, as is sometimes used in woodworking, the ratio would be 4 : 1·5, i.e., the roughness would be 4/1·5 times that of an 82-deg. wedge angle tool. For negative rake tools, the roughness will be smaller; if the equivalent roughness of a tool having a wede angle of 110 deg. were required, the values in the table would have to be reduced in the ratio of 1·25 : 1·5. The accuracy of the theoretical values for angles between 25 deg. and 110 deg. was proved by practical tests and very close agreement was

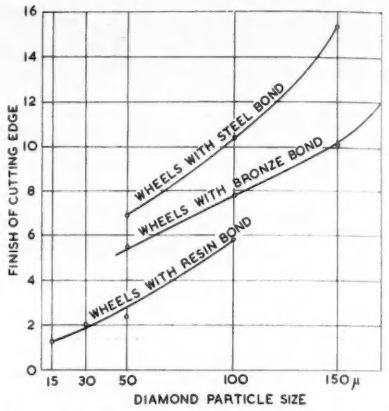

Fig. 10. **Differences in surface finish of the same carbide grade, ground with steel, bronze and resin-bonded diamond wheels.**

obtained. It therefore becomes possible to widen the field of application of the grinding wheel selection tables to all practical wedge angles by using the "wedge angle correction factor."

VIII. The Relationship Between Surface Finish and some Sintered Carbide Characteristics.

A parallel investigation was carried into the formation of fine hair-line cracks in a large number of various grades of carbide of German and other manufacture. These were compared immediately after brazing, after grinding, and after being used for cutting. The results were remarkably close to those found in the surface finish investigation. Carbides in the H 1 and G 1 groups thus showed only a very small incidence of hair-line cracks. The titanium carbide grades were more prone to crack formation and, in general, the quantity of hair-line cracks increased in the same manner as the surface roughness. It can further be seen from the table that an increase in titanium content within the titanium-bearing group corresponded to a deterioration of the surface finish. The best finish was obtained on

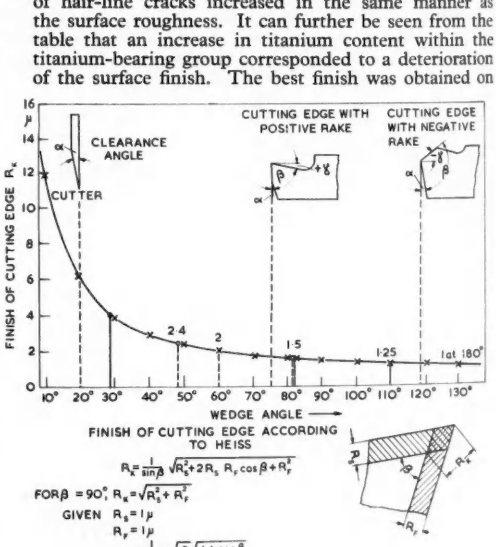
FINISH OF CUTTING EDGE R_x
μ
CLEARANCE ANGLE
CUTTER
CUTTING EDGE WITH POSITIVE RAKE
CUTTING EDGE WITH NEGATIVE RAKE
2·4
2
1·5
1·25
1 at 180°
10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130°
WEDGE ANGLE
FINISH OF CUTTING EDGE ACCORDING TO HEISS
$R_x = \frac{1}{\sin\beta}\sqrt{R_s^2 + 2R_s R_f \cos\beta + R_f^2}$
FOR $\beta = 90°$, $R_x = \sqrt{R_s^2 + R_f^2}$
GIVEN $R_s = 1\mu$
$R_f = 1\mu$
$R_x = \frac{1}{\sin\beta}\sqrt{2\sqrt{1+\cos\beta}}$
FOR $\beta = 90°$, $R_x = \sqrt{2} = 1{\cdot}4\mu$

Fig. 11. **The effect of wedge angle on the roughness of the cutting edge, with constant finish of rake and clearance faces.**

TABLE III. DIAMOND GRINDING WHEEL SELECTION TABLE FOR VARIOUS CARBIDE GRADES AND VARIOUS CUTTING EDGE FINISHES.

Carbide grade	Required cutting edge finish (roughness in μ)							
	Less than 1μ	1–1·6μ	1·6–2·5μ	2·5–4μ	4–6·3μ	6·3–10μ	10–16μ	16–25μ
F1		K–D7	K–D15	K–D30	K–D50 BZ–D30	K–D100 BZ–D50	K–D150 BZ–D100 (St–D50)	BZ–D150 St–D100
S1, S2, S3	K–D7	K–D15	K–D30	K–D50 BZ–D30	K–D100 BZ–D50	K–D150 BZ–D100 (St–D50)	BZ–D150 St–D100	BZ–D250 St–D150
*G1, G2, G3	K–D10	K–D20	K–D40	K–D70 BZ–D40	K–D120 BZ–D70	BZ–D120 St–D70	BZ–D200 St–D120	
H1	K–D15	K–D30	K–D50 BZ–D30	K–D100 BZ–D50	K–D150 BZ–D100 (St–D50)	BZ–D150 St–D100	BZ–D250 St–D150	

*In case these wheels are not available, they could be replaced by those specified for grade S 1.

K = synth. resin bond
BZ = bronze bond
St = steel bond

D7 = 5 to 10 μ particle size
D15 = 10 to 20 μ " "
D30 = 20 to 40 μ " "
D50 = 40 to 60 μ " "
D70 = 60 to 90 μ particle size
D100 = 90 to 120 μ " "
D150 = 150 to 200 μ " "
D250 = 200 to 300 μ " "

grade H 1, which has no titanium. With careful grinding, using a 15 μ resin-bonded diamond wheel, a finish of 0·5 μ could be obtained on this grade. According to Hinnüber, the structure of H sintered carbides contains almost exclusively fine-grained (0·5-3 μ), non-crystalline tungsten carbide particles, and this could be the reason for the excellent finish obtainable.

The whole object of the present investigation is in no way connected with publicising sintered carbides, the value of which is well known, but the determination of means by which required finishes can be obtained and finding methods of imparting good finishes to grades of carbides, which are rather difficult to deal with. Further work on this, and on the effect of tool finish on tool life and work finish, is planned.

GRINDING PROCEDURE AND STAGES.

It was found that there is a certain amount of overlapping of results obtained with different diamond particle sizes, and it is therefore possible to cover the whole range from rough to fine finish grinding with a small number of wheels of different bonds. The applications of the various bonds are as follows :

Steel-bonded wheels, which are fast-cutting, are most suitable for semi-finishing ; i.e., the next stage after roughing with silicon carbide wheels.

Bronze-bonded wheels impart a good finish to the tools and retain their form well. They can therefore be used for finishing.

Synthetic resin bonded wheels are slower in action than either of the metal-bonded wheels, but the obtainable finish is very much superior. For a given diamond particle size, the resulting roughness is only about one half. These wheels are therefore eminently suitable for fine finishing.

Considerable savings in operators' time could be effected by using diamond wheels instead of silicon carbide wheels, as the rate of metal removal is about five times higher. The following procedure could be followed :

Rough grinding : 150 μ diamonds, steel bond.
Semi-finishing : 150-200 μ diamonds, bronze bond.
Finishing : 100-150 μ diamonds, synthetic resin bond.
Fine finishing : 30 μ diamonds, synthetic resin bond.

It is clearly possible to obtain any required finish on any grade of carbide tool, and Table III serves as a guide for correct wheel selection. The selection of the most suitable wheels will also be influenced by the number of tools that have to be serviced, and rough grinding with silicon carbide wheels may be preferred. If, for instance, the number of diamond wheels is to be limited to two, grinding could follow this procedure :

Rough grinding : 46 K silicon carbide.
Semi-finishing : 80-120 J silicon carbide.
Finishing : 50 μ diamond, bronze bond, or 100 μ diamond, synthetic resin bond.
Fine finishing : 30 μ diamond, synthetic resin bond.

The value of the work described above could be further enhanced by extending it to cover other grades of carbide tools, and to take into account the effect of grinding wheel speeds and various grinding coolants or lubricants.

GRAVIMETRIC INVESTIGATION INTO THE OXIDATION OF COPPER-TIN ALLOYS

(*Concluded from page* 185)

characteristic behaviour of alloy (5) which at 500° C consists of $\alpha + \delta$ and is not very different from alloys (3) and (4), whilst at 600 and 700° C it contains the γ-phase only and differs markedly in oxidation behaviour.

(4) As the γ-phase disappears, oxidation resistance increases again. Alloy (6) consists of the δ-phase at 500° C and is practically inoxidizable, but at 600 and 650° C it contains stable γ and its oxidation resistance drops.

(5) In the stable region of the ϵ-phase, alloy (7), oxidation resistance again increases appreciably.

The oxidation resistance of copper-tin alloys thus depends not only on the tin content of the alloy and the nature of the oxide layer, but also, and perhaps foremost, on the nature of the stable phase at the temperature of oxidation. Where the formation of a phase leads to a decrease in free energy of the alloying metals, oxidation resistance increases. Thus, the α-phase is a primary solid solution, the β- and ϵ-phases are electronic compounds with electron atom ratios of 3 : 2 and 7 : 4. The γ-phase, however, has an irregular behaviour and the two metals in it retain their free energy nearly unaltered. The appreciable differences in the oxidation resistance of Cu-Sn alloys, even within fairly small temperature intervals, are the result of the frequent phase changes in the Cu-Sn system and of the difference in inherent oxidation resistance of the various phases.

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FRANCE

Grain Size and Permeability of Foundry Sands

By P. JASSON. (From *Fonderie*, No. 73, February 1952, pp. 2795-2804, 5 illustrations.)

IT is known that grain size and permeability of sands are interrelated in a general manner, but no quantitative, experimentally verifiable relationship has as yet been established. Nevertheless, Carman's equation[1], which gives the specific surface area S (in cm²/gr) of a powder sample in terms of its porosity and permeability in air, forms a convenient basis for an approximate theoretical approach. Considering the normal range of foundry sands only and assuming the sand to consist entirely of spherical grains graded in size by the American (A.F.A.) mesh scale, an approximate mean relationship $S = 2F$ is easily obtained, where F is the fineness number of the American specification. If this value is introduced into the Carman formula and the constants of this formula are evaluated for normal foundry conditions, we arrive at the modified equation

$$P = 88 \times 10^4 \frac{1}{F^2} \frac{(2{\cdot}65 - D)^3}{D^2} \quad .. \quad .. \quad (1)$$

where P is the permeability defined according to A.F.A. standards and D the specific density of the sand rammed into the mould, usually between 1·5 and 1·6.

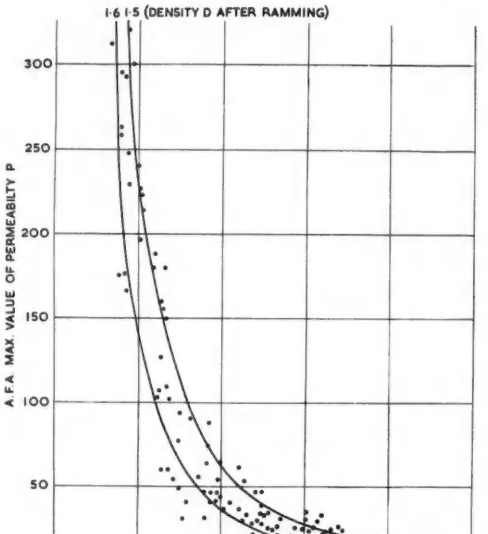

Fig. 1. **Experimental and theoretical permeability of foundry sands as a function of the grain size.**

Experiments show that the permeability of a given foundry sand varies with its moisture, increasing first with increasing water content, then passing through a maximum and, finally, decreasing as the water content rises further. Rather than take samples artificially freed of dust content, and thus untypical of foundry conditions, though perhaps more closely related to the conditions of eq. (1), one might use this maximum value of permeability of an actual foundry sand as its characteristic property, and compare it with the value obtained from eq. (1). Tests on 120 different foundry sands have, in fact, proved that the maximum value, if plotted against the A.F.A. fineness number F, closely corresponds to the expected theoretical value of eq. (1). Fig. 1 shows the experimental points with the theoretical curves for densities $D = 1{\cdot}5$ and $1{\cdot}6$. The coincidence is remarkable, considering that the dust content, the actual humidity, the mesh distribution, or the grain shape, have not been included in the theoretical analysis. All these factors appear to be of secondary importance only. In particular, the powder content (which is not included in the basic A.F.A. sieve analysis) does not seem to clog up the interstices between grains of sand, but appears to form envelopes around single grains, thus increasing their effective diameter and the permeability of the sample[2]. Closer examination of the samples not conforming to the theoretical values shows the following effects contributing to the deviations:

(a) Coarse sands that are difficult to mould often have an abnormally low density after moulding (1·3 to 1·4) and, hence, a higher permeability.

(b) Above a certain critical moisture, a high proportion of dust may lead to conglomeration of grains and, hence, to effectively larger grains and increased permeability.

(c) In an unfavourable mesh distribution, the smaller grains may fill up the interstices between larger grains, thus reducing the permeability.

(d) A high proportion of dry dust increases the specific surface area of the sample and lowers its permeability.

(e) Sharp-edged sand grains also increase the specific surface area and reduce the permeability.

All these effects may combine to produce serious deviations from the theoretical value. On the other hand, they also detract from the suitability of a sand for foundry purposes, e.g., a coarse sand which is difficult to ram produces a rough skin; excessive fine dust leads to blow-holes and blisters. A normal sand will usually conform to the theoretical values, which thus provide an important criterion for the choice of a suitable foundry sand as well as a check on the tests for permeability. If the casting is required to have a good smooth skin, the permeability of the sand must be kept as low as production conditions permit. If, e.g., a permeability of 100 is just permissible, then according to the theoretical curves, a sand of A.F.A. fineness number F between 60 and 80 should be chosen. Often the problem of improving the low permeability of too fine a sand is encountered. It is obvious from the curves that additions of coarser sand do not help much unless a very large amount is added, so that the characteristics of the sand are changed completely. In a particular example, a sand of fineness $F = 120$ and permeability $P = 25$ (A.F.A. standards) had to be modified to a value $P = 50$. The theoretical curves (Fig. 1) show that an average fineness $F = 90$ is required for this permeability. Hence, 100 per cent of sand $F = 60$ or about 80 per cent of sand $F = 40$ would be the required additions. A more rational method of improving the permeability of the original sand would consist in eliminating some of the fine powder constituents. Even a partial elimination would appreciably increase the effective mean grain size of the sand and, hence, also its permeability.

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New Materials, Processes and Equipment

LIGHTWEIGHT 3000 PSI COMPRESSOR

Although The Hymatic Engineering Company Ltd. of Redditch, Worcs., have designed this compressor primarily for aircraft use, it is ideally suited for other applications in industry by virtue of its performance and compactness.

The compressor, shown in Fig. 1, is a three-stage, air-cooled unit with a normal working pressure of 3000 psi and a maximum pressure, due to the relief valve setting, of 3300 psi. When running at its normal speed of 1500 rpm it has an output of 1·4 cfm, the air temperature being only 80° C. The compressor can run at 2000 rpm for periods not exceeding 15 minutes, this permitted overspeed catering for maximum engine speeds. Under normal atmospheric conditions an air cooling flow of 85 cfm is required, but when the atmosphere temperature rises to 40° C, as in the tropics, the cooling flow necessary is 150 cfm. The total weight of the compressor complete with intercoolers, relief valves and cowl is only 10 lb.

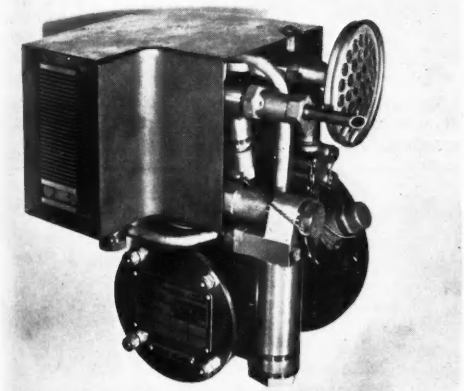


Fig. 1. **Hymatic compressor, type HC. 51, complete with intercooler, relief valves and cowl.**

The compressor embodies many interesting features, the most important of which is the truncated piston and stepped cylinder arrangement which provides excellent cooling in the second stage, the cooling surface area being high in relation to the volume. As approximately equal work is done in each stage, the torque fluctuation is reduced and the connecting rod is usefully employed during both strokes.

Several problems had to be overcome in the design of the crankshaft and piston assembly (Fig. 2). Lubrication of the upper piston rings is dependent upon the oil which passes the lower set of rings, but at the same time it is necessary to keep to a minimum the amount of oil delivered with the air. To control the oil consumption and to minimise air losses past the piston rings, the cylinder is finished to extremely fine limits. Very close control is exercised over the bore dimensions as well as the concentricity, freedom from ovality and surface finish. The diameters are controlled to 0·0006 in. and combined ovality and eccentricity must not exceed the same figure.

Air enters the first stage through a filter and then through an annular light-weight plate valve to the first stage cylinder. After compression, the air is delivered through a plate valve to a cooler and thence to the second stage inlet valve. Although cooling takes place in the second stage, it is still necessary to cool it further before it enters the third stage, and finned light alloy coolers are provided for this purpose.

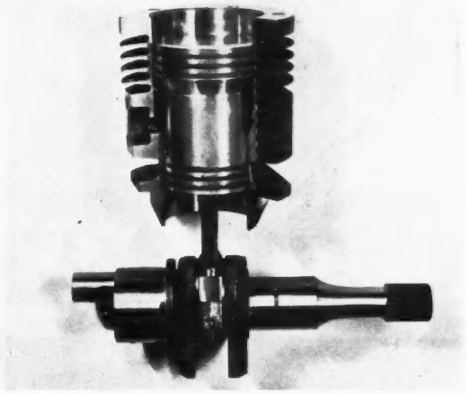


Fig. 2. **Crankshaft and piston assembly.**

The third-stage components include a scotch crank mechanism to operate the plunger. The slipper block and crosshead are made from cast iron, a departure from aircraft technique but a combination which has proved eminently satisfactory. A similar material is used for the cylinder, which has aluminium fins bonded to it by the Al-Fin process. The piston has no rings and the gas seal is maintained by using a running clearance of 0·00015 in.

The compressor is being developed for a variety of applications, some of them requiring increased output at high altitudes. This is achieved by boosting or supercharging, the air being obtained from the aircraft cabin blower or the turbine engine. In yet another application there is no cooling air available and a small high-speed centrifugal fan has been built into the compressor to make it independent of an outside source.

CONTINUOUS TUBE FORMING AND WELDING MACHINE

The Bronx Engineering Co. Ltd. of Lye, Worcs. have recently completed a machine for continuous production of welded tube in diameters from ½ in. to 2½ in. and from 20 to 10 s.w.g. This machine is being supplied to a firm in South America. The machine described incorporates an oxy-gas welding unit but, alternatively, an electric welding head can be supplied if desired. The designed speed is from 40 to 120 fpm.

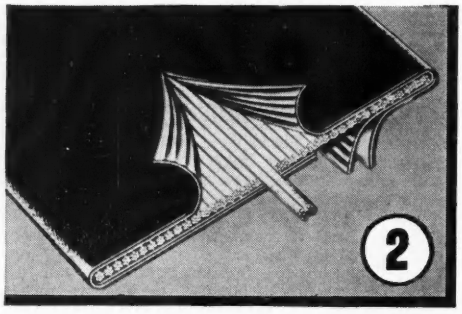
As will be seen from Fig. 1, the machine consists of a forming unit, an oxy-acetylene welding unit, a sizing and straightening unit, a flying cut-off, and a run-out and discharge table.

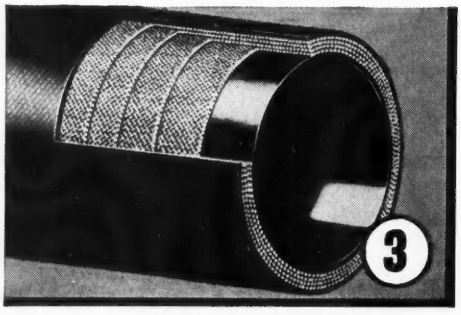
Ancillary units are interposed between the major items and comprise a tube guide prior to the welding unit, a weld trimmer after the welding unit, and a discharge roll at the entry end of the run-out and discharge table.

The forming unit consists of six horizontal forming rolls, preceded by a guide bracket and supporting rollers

BELTING AND HOSE

that can carry the load . . . and keep on carrying it





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1 GOODYEAR CONVEYOR BELTS

The "Stacker" belt, illustrated here, is designed for installations which handle highly abrasive material and subject the belt to frequent flexing. Its tough, resilient cover " gives " under impact and resists cutting. Superior frictioning between the high-grade plies ensures that severe flexing will not cause ply separation.

2 ENDLESS CORD TRANSMISSION BELTS

Specifically built for modern high-speed, small-pulley machinery, Goodyear Endless Cord Transmission Belts incorporate a patent *balanced* construction of load-carrying cords. Their H.P. capacity is 33⅓% greater than ordinary belts of equivalent thickness; they are genuinely endless; and have an unusual degree of flexibility which gives a firm grip on small pulleys at high speeds.

3 WRAPPED PLY HOSE

This Goodyear Hose is built from high-grade rubber tube wrapped in tough rubberized fabric for greater strength. A protective cover of bruise- and abrasion-resisting rubber assures lasting wear. And scientific arrangement of the fabric plies minimizes kinking. Intended for general service this wrapped ply hose gives long life under the most arduous conditions. It is typical of the several styles of Goodyear hose built for delivery of air, water, steam, chemicals, foods, paint, solvents or petroleum products.

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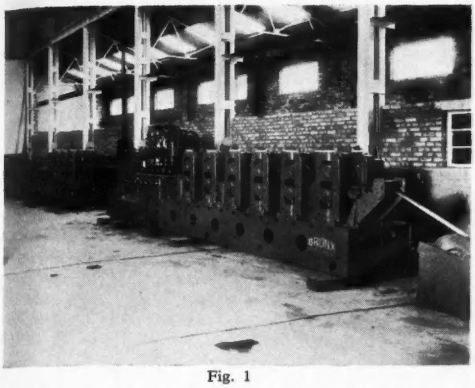

Fig. 1

for the strip feed. The forming roll spindles are each supported at the inner end by twin tapered roller bearings, the outer bearings being Hyatt type rollers.

On either side of the final horizontal forming roll there is a set of vertical rolls, the outer of these giving the final contour to the tube prior to welding.

The strip, which has now become a tube, goes into the welding unit via a tube guide consisting of a blade which runs between the tube's abutting edges and thus ensures that the joint is kept in line beneath the welding head. The tube then passes between six sets of laterally adjustable rolls, each roll being water-cooled by means of branch pipes under the machine which are taken to the hollow roll spindles.

The cooling water passes up through the spindle and is fed via two small-branch pipes into the cup formed by the hollowed-out roll, and subsequently overflows through an annulus in the centre of the roll into a trough under the bed of the unit.

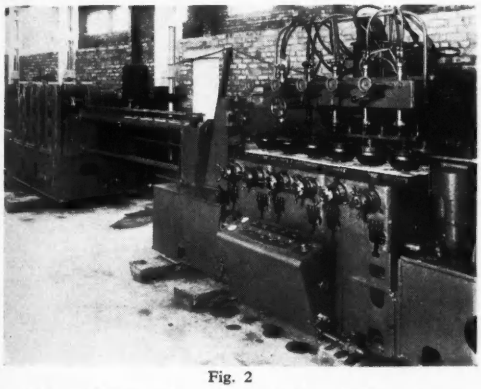

Fig. 2

The welding unit proper, shown in Fig. 2, was designed and supplied by The British Oxygen Co. Ltd. It consists of five blowpipe bodies, each carrying a flat head with a multiple nozzle array. The first four sets of nozzles are for heating only and the final set is the actual welding head, 41 nozzles being arranged in a single row. Individual height and lateral adjustment is provided for the nozzle heads by mounting them on a beam disposed centrally over the table. Vertical adjustment of each head is effected by means of five control levers, each actuating an eccentric. The lateral movement is given by a worm nut mechanism with five small handwheels. The beam is supported by a saddle riding on a pillar behind the unit, and is set to the correct height by a stop, which is adjusted by a handwheel at the front of the welding unit.

The blowpipe shanks and the nozzle units are cooled by water which passes down around the blowpipes into the nozzle heads and is allowed to overflow via small diameter tubes into the cups of the rolls.

Immediately under the portion of the tube being heated and welded, there is a slotted channel faced with asbestos. The slot is the entry for an exhaust duct running along the centre of the welding unit, the fumes being extracted by a centrifugal blower.

Test runs on 1¼ in. dia. × 14 s.w.g. material gave welds with 100 per cent penetration and good fusion. Pieces from sample welds were subjected to 90 deg. bend tests without signs of cracking.

The weld is trimmed by a tool which is mounted in a tool post for adjustment. The cutting face is ground slightly concave to accommodate different tube diameters and support is given by a roller immediately under the tube. The trimmer is mounted at the entry end of the sizing and straightening unit, which comprises three sets of rolls. Following the sizing and straightening rolls, there is a flying cut-off, the return ram and tube clamp of which are pneumatically operated. The cut-off wheel running at 3600 rpm is of the abrasive type and is 16 in. in diameter. Its traverse across the tube is arranged by a pick-up wheel running up an inclined ramp as the cut-off head travels down the length of the unit. This arrangement gives a rocking motion to the cut-off head. The length of the cut tube is varied by an adjustable limit switch on the discharge table which can be set for 10 ft to 20 ft lengths.

The discharge pinch roll runs at a higher speed than the main rolls so that, when the tube is severed, the cut portion is accelerated so as to increase the gap between it and the following section.

It will be observed that all of the rams, clamps and ejector mechanisms are operated pneumatically and an air supply at 300 cfm and 75 psi is required for this purpose.

The main rolls of the machine are driven by a 25 hp variable speed d.c. motor running at 500 to 1500 rpm, the drive being via V-belts to the machine and thence through chain couplings to the forming, sizing and straightening rolls. The exhaust fan is driven by a separate motor.

CALCULATION OF THICK-WALLED CYLINDRICAL SHELLS

(*Concluded from page* 188)

The same formula is applicable, according to Bailey, to determine the rupture of the pipe. The stress s in eq. (16) now represents the stress in a tensile creep test causing rupture after the same period of service as the lifetime of the vessel. Brittle intergranular fracture has not been found to occur in carbon steel at suitable temperatures with creep elongations below certain critical values, and therefore eq. (16) is applicable to determine both deformation and rupture. Bailey's equation has also been applied to steam pipes.

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CLASSIFIED ABSTRACTS

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AERODYNAMICS

Measurement of Recovery Factors and Friction Coefficients for Supersonic Flow of Air in a Tube

By J. KAYE, J. H. KEENAN, K. K. KLINGENSMITH, G. M. KETCHUM and T. Y. TOONG. (From *Journal of Applied Mechanics, U.S.A.*, Vol 19, No 1, March, 1952, pp. 77-96, 14 illustrations.)

FOR the past few years a program has been under way to obtain reliable data on the rate of heat transfer to air moving at supersonic speeds. The investigation was limited to air flowing at supersonic speeds in a round tube. The program was divided into two separate parts, the first for measurement of the adiabatic wall temperatures of a supersonic stream and the second for the heat-transfer rate. The first part of this program is described in this article. The details of three experimental test combinations used to measure the adiabatic wall temperature and local state of a supersonic stream of air are presented. The experimental data for forty runs, in the form of measured pressure and temperature distributions, are included. The range of diameter Reynolds number covered is from $0{\cdot}15 \times 10^5$ to 5×10^5. The length Reynolds number extends to 120×10^5. The Mach number at the inlet to the round tube is about 2·6. The calculated quantities such as the local apparent friction coefficient, recovery factor, local Mach number and so forth, are obtained from the simple one-dimensional flow model for which the properties of the stream are uniform at any cross-section of the tube, and boundary-layer effects are ignored. A subsequent paper will deal with the calculation of these quantities when account is taken of the boundary-layer growth in the tube on the basis of a two-dimensional flow model.

BLOWERS AND COMPRESSORS

Surging in Centrifugal and Axial-Flow Compressors

By R. O. BULLOCK and H. B. FINGER. (From *SAE Quarterly Transactions, U.S.A.*, Vol. 6, No. 2, April, 1952, pp. 220-229, 9 illustrations.)

THE tendency toward high overall compressor pressure ratios in our present-day turbojet engines, intended to improve the engine fuel economy characteristics, has imposed the problems of starting and accelerating which emphasize the need for understanding the surge phenomenon.

Compressor surge is an unstable flow condition characterized by pulsations of the flow which, besides causing appreciable power reduction, have in some cases caused engine failures. It is, therefore, apparent that engine operation in this region is not permissible and means must be found to avoid such unstable operation. Because comparatively low compressor pressure ratios have been used up to the present time, it has been possible to avoid engine operation near the surge region by matching the compressor and the turbine in such a manner that the distance between the engine operating point and the surge point is safe. However, for overall pressure ratios in excess of 7 or 8, it appears that this method of circumventing the surge problem becomes impractical.

This paper reviews the work done in anlayzing the causes of surge and in investigating the effects of compressor operating conditions on the character of the flow variations that occur during surge. A comparison of flow conditions in the centrifugal and axial-flow compressors is presented to shed further light on the causes and characteristics of the surge phenomenon. It has been found that eddies may arise within the flow through compressors which make the surge characteristics of centrifugal and axial-flow compressors similar. The effect of matching the stages of an axial-flow compressor at various design points is presented to indicate the importance of the effect of stage matching in extending the surge-free operating range of a compressor. Several other methods of inhibiting surge are discussed, based on analysis of the flow stability and the stage performance characteristics.

The principal conclusions which have resulted from this investigation are :—

1. The compressor surges as a unit with the flow pulsating at the same frequency throughout.

2. Surging may actually be only one of many undesirable manifestations resulting from the attempt to operate a compressor beyond the envelope line of its potential performance curve.

3. Stalling of any given stage in an axial-flow compressor is not a sufficient condition for surge ; because a positive slope appears to be a definite criterion for instability, the increase in the algebraic value of the operating slope of any stage is to be avoided.

4. A universal cure-all for surging does not exist at the present time, but ingenious application of the fundamental knowledge now available should permit definite improvements to be made in the off-design operation of any given compressor.

METALLURGICAL ENGINEERING

The Use of Isoactivity Lines in Ternary Phase Diagrams

By M. HILLERT. (From *Jernkontorets Annaler, Sweden*, Vol. 136, No. 2, 1952, pp. 25-37, 14 illustrations.)

IT is shown that in isothermal sections of ternary phase diagrams compositions of constant activity for each component may be represented by contour curves, called isoactivity lines. A useful general property of such lines is formulated and the value of this property demonstrated in five applications.

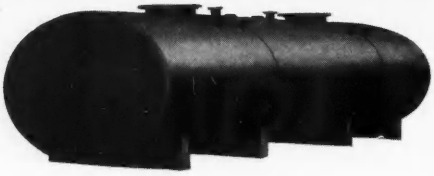
(1) A proof is presented for the statement that the two-phase region for a so-called " para-state " is smaller than that for the corresponding " ortho-state."

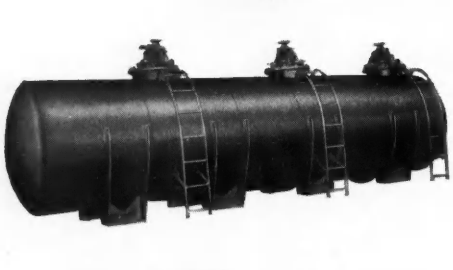
(2) An earlier explanation for the fact that, during carburizing of nickel steels, no surface zone containing carbide is formed, has been shown to be untenable on thermodynamic grounds.

(3) The direction of " up-hill " diffusion of carbon in some alloy steels has been deduced from the phase diagrams.

(4) The general relation has been demonstrated between the cementite (or graphite) stabilizing property of an alloying element and the direction of the tie-lines austenite/cementite and ferrite/cementite.

(5) The possible appearances of the tie-line triangle for the eutectoid equilibrium austenite $\rightleftarrows$ ferrite + cementite have been discussed. Two of the eight possible cases are less probable than the others but are not theoretically excluded.





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STRENGTH OF MATERIALS

An Experimental Investigation of Over-Straining in Mild Steel Thick-Walled Cylinders by Internal Fluid Pressure

By M. C. STEELE and J. YOUNG. (From *Transactions of the ASME, U.S.A.*, Vol. 74, No. 3, April, 1952, pp. 355-363, 12 illustrations.)

THEORETICAL analyses of thick-walled cylinders subjected to internal uniform pressure have been carried out before. Accurate solutions for the all-elastic, elastic-plastic, and fully plastic cylinders are well known. Differences in treatment lie in the assumptions regarding the plastic stress-strain relations and flow condition of the plastic material. In all cases the elastic-plastic boundary is taken to be circular and the cylinder to be comprised of two regions, an inner plastic and an outer elastic one, both of homogeneous material. The yielding of mild steel is characterized by the formation of wedge-shaped veins of overstrained material, and it is doubtful whether the theories, so far presented, can describe adequately the stresses and deformations in a mild-steel cylinder.

Techniques have been developed in this investigation to measure strains at the bore surface of thick-walled cylinders and to observe the formation and propagation of Lüders' lines on the end faces and outside surfaces. They are applied to an experimental investigation of mild-steel cylinders of 2 : 1 wall ratio.

The mechanism of yielding in mild steel is characterized by the formation of wedge regions of overstrain. The plastic material occupies a very small volume of the total. This conflicts with the conventional theoretical assumptions which predict regions of elastic and plastic isotropic material connected by a rotationally symmetric boundary. As a consequence, measured bore, outside circumferential and axial strains show discrepancies with theory.

Bore strain measurements predict initial yield to commence at a pressure calculated using Tresca's maximum shear-stress theory of failure. This is not observed on the outside-diameter circumferential measurements because of the aforementioned mechanism of yielding in mild steel.

Fully plastic values of pressure (i.e., where the pressure versus strain curves become parallel to the strain axis, which corresponds to one or two wedges reaching the outside surface) are lower than those predicted from Sopwith's theory and considerably in error when compared with that of MacGregor, Coffin, and Fisher. Thus, it must be concluded that theory predicts unsafe values for the load-carrying capacity of mild-steel cylinders.

There are marked time effects (creep) which require further investigation. They are observed over periods up to 100 min, but the authors believe they should be investigated over much longer periods of time.

WELDING

Welded Joints Between Dissimilar Metals in High-Temperature Service

By R. W. EMERSON and W. R. HUTCHINSON. (From *The Welding Journal, U.S.A.*, Vol. 31, No. 3, March, 1952, pp. 126s-141s, 28 illustrations.)

THE work reported here deals essentially with the problem of carbon migration across a low-alloy ferritic-high-alloy austenitic interface and is only one of the problems involved in making a welded dissimilar metal pipe joint which will give satisfactory service performance at elevated temperatures.

Carbon migration in itself is not believed to be a serious problem. The rate of diffusion of carbon at 1050° F is relatively slow and is believed to be of little significance. High-temperature postweld heat treatments, however, will result in rapid carbon migration and such treatments for any prolonged period of time would result in more cargon migration than would be obtained in many years at the service temperature. High-temperature postweld heat treatments are, therefore, to be avoided.

In placing dissimilar metal joints in service, excessive temperature cycling should be avoided, particularly when the high-temperature side of the cycle is in the scaling range of the low-alloy ferritic steel.

Dissimilar metal joints have, in the past, given quite satisfactory service and should continue to do so provided (1) excessive carbon migration has not been developed by high-temperature postweld heat treatments; (2) the operating temperature is relatively uniform; (3) the surface stability of the low-alloy ferritic material is adequate for the maximum service temperature.

WIRE AND WIRE PRODUCTS

Pre-Plated Drawn Steel Wire Saves Scarce Metals

By H. KENMORE. (From *Materials and Methods, U.S.A.*, Vol. 35, No. 5, May, 1952, pp. 96-98, 4 illustrations.)

ELECTROPLATED wire which can be drawn, formed and otherwise processed without flaking of the coating is a relatively new development which is of particular significance during this period of metal shortages. By using a plating of copper or nickel on steel wire, instead of solid wire of these scarce metals, savings of over 90 per cent can be effected.

Briefly, in this process a heavy coating of the desired metal is first electroplated on steel core wire and then the plated wire is drawn down to size by conventional drawing methods. The plating operation is continuous and automatic. Excellent adhesion is obtained by a special method of pre-treatment and intermittent coating of the steel surface before the desired metal covering is applied.

Low, medium or high carbon steel is used for the core wire, depending on the application. The initial diameter of the base wire is from 5/16 to 1/4 in. In the course of the drawing process the coated wire is annealed similarly to bare steel. The finish anneal is carried out at 1150° F and an atmosphere furnace is used to give a bright finish. By means of this process, wire is obtained which (1) has a uniform coating throughout the length of wire, (2) has a coating which is an integral part of the base wire, and (3) has the properties of cold-worked steel plus the properties peculiar to the particular coating metal used. The mechanical properties of drawn plate wire are essentially the same as those of drawn unplated steel wire of the same composition. One of the principal features of this wire is that it can be further shaped and worked by bending, flattening, swaging, and even thread rolling operations without chipping or flaking of the coating.

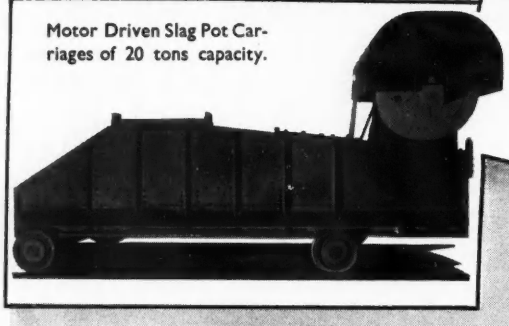
Because of the present-day scarcities, copper, brass and nickel plated steel wire are now receiving most attention from industry. However, nickel on copper and silver on copper are also available for suitable applications.

Finally, the most recent development has been electroplating stainless steel wire by the same process.

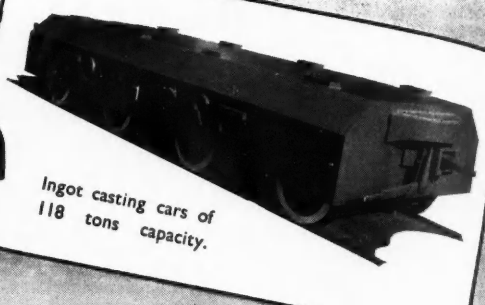
WHO CAN HELP?

We have received an enquiry from one of our American readers asking us where he could obtain a specimen of a spiral slide rule invented and patented (No. 28,603) by Dr. Walter Ellsworthy Lilly in 1912 while he was Head of the Engineering School of Trinity College, Dublin. Will anyone able to give any assistance in this connection please communicate with the Editor?

IRON AND STEELWORKS TRANSPORT EQUIPMENT



Motor Driven Slag Pot Carriages of 20 tons capacity.



Ingot casting cars of 118 tons capacity.

These are some examples of equipment which we have supplied for the new Abbey Works. Other equipment includes Roll Transfer Bogies, Coil Carrying Bogies, Crop Skip Bogies, Steel Casting Ladles and Carriages, Hot Metal Ladles and structural steelwork for Soaking Pits.

Slab Transfer Bogies of 80 tons capacity.

Double Slag Pot Carriages of 100 tons capacity.

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NEWS OF THE MONTH

PERSONAL

Mr. F. H. Brooks, general works manager of The Wellman Smith Owen Engineering Corporation Ltd., Parnell House, Wilton Road, London, S.W.1, has been elected a director of the Company.

Mr. J. G. Bruce, A.M.I.E.E., A.M.I.Loco.E., has been appointed acting assistant mechanical engineer (works), and **Mr. G. Clark,** production engineer (Acton works) in the department of the chief mechanical engineer (railways) of the London Transport Executive.

Mr. W. Lindsay Burns has been elected chairman of Henry Balfour & Co. Ltd., Leven, Fife. He is also chairman of George Scott & Son (London) Ltd., Ernest Scott & Co. Ltd., and vice-chairman of Enamelled Products Corporation (1933) Ltd.

Mr. Christopher Dykes, M.A., M.Sc., formerly chief engineer (development) of B.O.A.C., has started practice as advising aeronautical engineer at 31 Pembroke Gardens, London, W.8.

Mr. H. G. Herrington has been appointed managing director of High Duty Alloys Ltd., Slough.

Dr. R. B. Killingsworth, of the Socony-Vacuum Oil Co., Inc., New York, has been appointed manager of a newly formed large technical department of the Vacuum Oil Co. Ltd., Caxton House, London, S.W.1.

Sir Charles S. Lillicrap, K.C.B., M.B.E., Director of Naval Construction, Admiralty, until September, 1951, has been elected a director of J. Samuel White & Co. Ltd., Cowes, Isle of Wight.

Mr. A. J. Sear, who has been a director of W. B. Dick & Co. Ltd. for 25 years, has been appointed managing director of the Company.

Mr. Walter Symes has resigned from the positions of director and works manager of the Trafford Parks works of Metropolitan-Vickers Electrical Co. Ltd., in order to become manufacturing consultant of Associated Electrical Industries Ltd., Crown House, Aldwych, London, W.C.2. **Mr. Arthur C. Main, M.I.E.E.,** has been appointed works manager at Trafford Park and a director of Metropolitan-Vickers Electrical Co. Ltd.

Mr. Peter Tennant, deputy director, has been appointed, on the retirement of **Mr. Charles Ramsden,** overseas director of the Federation of British Industries.

Mr. P. E. Thomas, A.M.I.Mech.E., has been appointed technical representative for London and S.E. England for Northey Rotary Compressors Ltd., Parkstone, Dorset.

Sir Cecil Weir, K.B.E., M.C., D.L., has been elected President of the Institution of Production Engineers, in succession to **Major-General K. C. Appleyard, C.B.E. Mr. Harold Burke, M.I.Mech.E.,** has been elected Chairman.

BUSINESS NOTES

Sparcatron Ltd., a new company, has been formed to grant licences throughout the world, under the Rudorff and other patents, for the application of the new process of electronic machining of materials. The Company has set up laboratories for pure and applied research in this field at Tuffley Crescent, Gloucester.

The process is of particular value for the machining and finishing of the harder materials and those which are exceedingly difficult to form by conventional methods.

The new Company has been formed by the Bath & Portland Stone Firms Ltd., who also control Impregnated Diamond Products Ltd. Gloucester.

A FILM ON MATERIALS HANDLING

It has been stated that "Every time a material is handled, something is added to its cost and nothing to its value." How true this is, is demonstrated in the early part of the film, "A Case For Handling," which leads to the conclusion that more efficient handling methods make for increased production and fewer rejects. This film, which has been produced by the British Electrical Development Association, was shown for the first time at the Mechanical Handling Exhibition at Olympia.

The film shows that materials handling, properly applied can do away with heavy labouring work and give people the chance of better jobs with more pay and a higher standard of life, with a large reduction of accidents by the elimination of heavy lifting, and shifting.

The film, after depicting a factory where much of the work is still done by hand, shows three men touring a reorganised factory to see the improved materials handling in action, with sequences taken at a number of factories producing a wide variety of products from foodstuffs to engineering parts.

The commentary and dialogue throughout explain clearly what the equipment is for and what is being achieved. Among the points made are "The need for increased productivity it is familiar cry these days, but it won't be got only by telling people to work harder or for longer hours," and, "In British industry today, probably the greatest source of wasted time and labour is in unnecessary handling. In heavy engineering for example, often 50 tons of material is moved around in the course of producing a single ton of finished goods. The greatest possibilities of immediate improvement are to be found in the field of materials handling, and the more everyone in industry realises this the better."

The film ends with the doubting visitor becoming convinced of the value of materials handling, particularly when he hears, "When the scheme got under way, the firm needed *more* men not *less*, to cope with the increased output."

The shots were taken in a number of large modern factories. Among the many leading manufacturers who co-operated with E.D.A. to make this film a success, were :—Hoover Ltd., Perivale, Middlesex; Dunlop Rubber Co. Ltd., Fort Dunlop, Birmingham; Midland Electric Manufacturing Co. Ltd., Tyseley, Birmingham; Fisher and Ludlow, Birmingham; Guest, Keen and Nettlefold Ltd., Birmingham; Heinz Ltd., Harlesden, N.W.; McVitie and Price, London, N.W.10; Jas. Pascall and Son Ltd., Mitcham, Surrey; Harris Lebus Ltd., Finsbury Works, N.17; W. M. Davis Ltd., Slough; John Dale and Co. Ltd., London Colney, St. Albans; Goodban Ltd., Drapers, Chiswick High Road, W.4; and British Railway Executive, Marylebone Road, N.W.1.

THE BASIC PRINCIPLES OF LUBRICATION

A film produced for the Esso Petroleum Co. Ltd. is a lucid and definitive exposition of the basic principles of lubrication. It is divided into four parts, dealing respectively with Friction, Fluid-film lubrication, Boundary lubrication and Extreme pressure lubrication.

Full use is made of laboratory experiments, micro-photography, animated diagrams and radio-active techniques. Beginning with an explanation of the elementary laws of friction, the theme is developed in logical sequence, and the film illustrates much of the fundamental research into the behaviour of lubricants and surfaces on which present-day knowledge of this subject is based.

The object throughout has been to make a film which, within a period of some fifty-five minutes, gives an authoritative explanation of the phenomena with which specialists in lubrication are concerned.

Throughout the planning, making and editing of the film, Dr. F. P. Bowden acted as Scientific Adviser, and considerable use has been made of the results of work carried out by him and under his direction.

Esso Petroleum Company Limited will use the film for instructional and training purposes within their own organisation. Copies will also be available for exhibition to audiences at Universities, Technical Colleges, Research Organisations, Trade Associations and Societies and others to whom it may be of interest and value.

Applications for the loan of 16 mm. copies should be made to: The Manager, Industrial Sales Department, Esso Petroleum Company, Limited, 36, Queen Anne's Gate, London, S.W.1.

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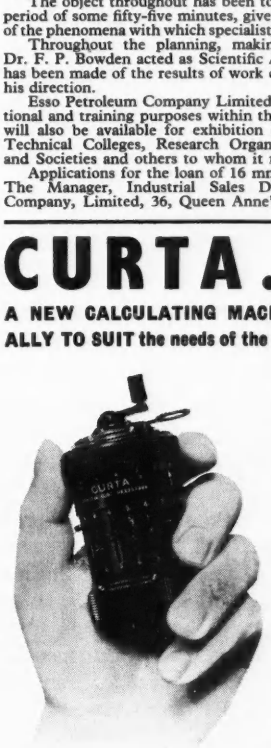

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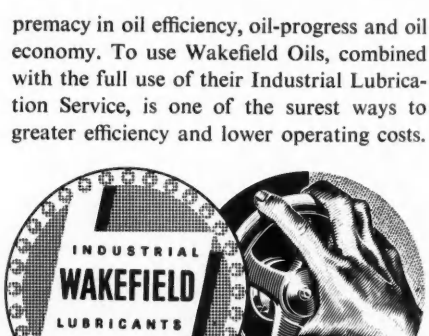

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QUANTITY PRODUCTION OF GLASS BULBS

The British Thomson-Houston Co. Ltd. and The General Electric Co. Ltd. have jointly formed a new company, Glass Bulbs Ltd., with a factory at Harworth, near Doncaster, Yorkshire, which is capable of producing one-and-a-half million glass bulbs a day. Production of all the bulbs required for Mazda and Osram general lighting service lamps is being concentrated at this factory; in addition to this, the output is sufficient to meet the requirements of all other lamp manufacturers in the British Isles and to allow an ample margin for export to Europe and the Commonwealth. This vast production has been made possible by the installation of two ribbon-type machines which are the only ones of their kind outside the United States.

The factory building is 700 ft. long by 80 ft. wide, and there are over 600 employees. The plant comprises the main factory building housing the furnace, ribbon machines, annealing lehrs, inspection point, packaging lines, chemical laboratory, stores, workshop and main offices. At one end is the 100 ft. mixing tower where the raw materials are taken in, and it is from this point that the manufacturing process begins, terminating in the finished products which, packed in cartons, are transferred on a conveyor belt to the finished bulb stores where they are loaded directly into railway wagons.

The entire scheme of manufacture is based on a system of flow production and is highly mechanised throughout.

The mixing tower is the only one of its kind at any glass works and presented some unique problems in structural engineering. It consists essentially of seven silos, extending from the top to the bottom of the tower, each of which is capable of holding 1,500 tons. The raw materials consist of soda ash, dolomites, limestone, sand and felspar in addition to cullet, or surplus glass, which is fed to its silo by a mechanical bucket conveyor inside the building. All these materials are obtained in this country.

The raw materials are reclaimed mechanically from shelves at the top of their respective silos and pass down chutes to the automatic weighing machines two floors below whence they are discharged in their correct proportions into a rotary mixing drum.

On the floor directly below the outflow at the top of the tower are situated the remote control panels which give an accurate and instantaneous picture of the progress of events. A small staff of two men is able to supervise the working of this important section.

From the mixing drum the thoroughly blended materials are automatically discharged into canisters which are mechanically conveyed on a roller runway to the hopper from which the furnace is fed. The hopper discharges into the electrically operated, mobile screw feeders which force the charge, or batch, into the mouth of the furnace.

The furnace is a continuous tank type cross-fired regenerative furnace capable of producing 150 tons of glass a day. It is fired with coke oven gas and the regenerative feature enables the incoming air to be pre-heated before entering the furnace.

Temperatures are suitably graded through the melting and refining ends, the glass finally passing through the forehearths, which are of the most modern automatic type, and which bring the glass to the exact temperature required for feeding to the ribbon machines. Pressure in the furnace is maintained automatically at slightly above atmosphere.

On leaving the forehearth a controlled stream of glowing, molten glass flows down between two rotating water cooled rollers at one end of the ribbon machine. One roller has a plain surface, the other contains pockets, or circular depressions, so that the glass issues from between them as a continuous ribbon bearing a series of shallow circular protuberances or "humps" in appearance resembling the ribbon of "caps" used in a boy's toy pistol. On leaving the rollers the ribbon is carried on a continuous belt of orifice plates, each of which is pierced with a circular hole that comes accurately into position beneath a "hump." Moving forward on the orifice plates the ribbon meets a continuous chain of blowheads which descend on to it from above, each blowhead pressing into the centre of a "hump" directly over a hole in each orifice plate.

A puff of compressed air issuing from the blowhead causes the "hump" to be extruded downwards through the hole in the orifice plate, the function of which is to determine the diameter of the flare at the top of the neck of the finished bulb. These embryonic bulbs, or glass blanks as they are called, hanging below the rapidly moving ribbon, increase in depth until they meet the split moulds which rise from below on a continuous belt and close round them from both sides. The moulds now begin to rotate and meanwhile the air pressure from the blowheads increases so that the glass blanks are moulded to their final shape. During this operation the ribbon, blowheads and moulds are all moving forward together at the same speed. On completion of this process the moulds open, revealing the bulbs, and return on their belt under the machine. Similarly the blowheads break contact with the glass ribbon and return along the machine on the upper side of their chain. The orifice plates, carrying the ribbon with the blown bulbs depending from beneath it, continue to travel forwards while jets of cooling air play upon the completed bulbs. On reaching the rotating ribbon lifter the bulbs are successively tapped off by the strokes of a synchronised hammer and fall into the scoops of a rotary turntable which tip them on to a moving belt for conveyance through a gas-fired lehr, or annealing oven. The glass ribbon passes down to the floor below where it is watercooled and subsequently broken up for re-use as cullet, while the orifice plates return horizontally behind the machine.

The moulding of the bulbs is essentially a very delicate and precise operation and for this reason the moulds are cork lined. The heat of the glass transforms the cork into fine carbon which readily absorbs water from the cooling sprays that play on the moulds as they pass back under the machine. Coming into contact with the hot glass, the water is vaporised, so that the bulbs are formed in a cushion of steam which leaves them with a polished surface finish.

The two ribbon machines are of different sizes: the larger one has a pitch of 3·9 ins. from centre to centre of the orifice plates, the smaller a pitch of 3 in. The pitch dimension naturally determines the size of bulb which can be blown. There are in all, seven different sizes of orifice plate, and rollers of two different depths of pocket: $\frac{7}{32}$ in. and $\frac{5}{32}$ in. respectively. These adequately cover all the sizes of bulbs and valve envelopes produced.

An important characteristic of the ribbon machine is that it is much more versatile than any other bulb blowing machine. It will blow the miniature type of valve bulb at a very high speed and can be quickly turned over to the production of large size filament lamp bulbs. A further important feature is the consistency of the product and its constant dimensional accuracy which greatly exceeds that previously obtainable from any other machine.

Each ribbon machine is driven by a 10 h.p. compound wound D.C. motor supplied from a three-phase full-wave rectifier and operated under electronic control so arranged as to maintain constant speed at any setting within $\pm\frac{1}{4}$ of one per cent for a 10 per cent variation in voltage. This form of control enables the motor speed to be varied from a crawl to 1750 r.p.m.

The larger machine, with moulds at 3·9 in. centres, produces from 350 to 500 bulbs a minute in the 70 mm, 75 mm and 80 mm sizes for 75 watt, 100 watt and 150 watt general lighting service lamps. Operating on a continuous 24 hour schedule, this machine gives a daily output of approximately 500,000 bulbs. The smaller machine, in which the mould centres are at a 3 in. pitch, will produce the whole range of valve bulbs up to 44.5 mm diameter, including all the miniature types, and lamp bulbs from the 25 mm stop and tail light size up to and including the 65 mm bulb for the 60 watt general service lamp. The output of this machine, which runs continuously throughout the 24 hours, is approximately 1,000,000 bulbs daily.

After annealing, the bulbs are air cooled while proceeding on a conveyor belt to the packers. At the control point five bulbs are picked off the belt every twelve minutes for examination and dimensional checks, continuous inspection being carried out on a quality control basis.

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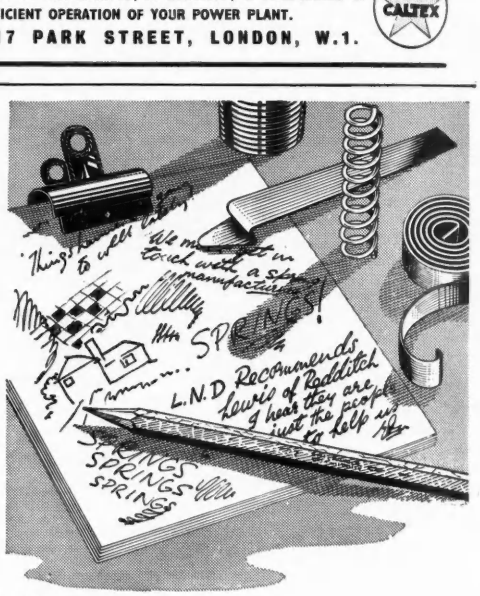

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This standard gives information on the principles of sieving as well as on the equipment to be used. It then proceeds to define the method by which the sample should be prepared for the test and the weight of sample to be taken. The sections that follow deal with the removal of fine dust by both the dry and wet methods. The actual sieving procedures are sub-divided into those dealing with hand sieving to the 'end point' by the rate test, machine sieving to the 'end point' by the rate test and a routine sieving test. Other sections deal with such subjects as loss of dust during sieving, sieving tests on materials with only a small weight of oversize on the sieve, and the method of reporting results and accuracy of results.

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